A Measurement on Electromagnetic Noise and Change of Surface in Arcing Electric Contacts

Yasuo Ebara, Toshiaki Koizumi, Hideaki Sone, *Member, IEEE*, and Yoshiaki Nemoto, *Member, IEEE*

***Abstract*—The authors have observed the relationship between waveform of electromagnetic noise and change of surface for opening Ag-Pd electric contacts. In case of Ag-Pd electrodes, continuous noise is observed in the whole period of arc discharge in both current polarities. Fluctuations of arc voltage and noise are large in the middle part of arc discharge duration. The noise decreases in the later half. The authors proposed a classification of noise waveforms and pattern of surface changes. As these results, patterns of noise waveform and changes of electrode surface at various circuit conditions are classified into three categories. In this paper, the authors showed the correlation between pattern of noise waveform and the change of electrode surface.**

***Index Terms*—Arc discharge, change of surface, electric contact, electromagnetic noise, statistical analysis.**

I. Introduction

An electric contact in a small electric appliance is considered as an electromagnetic noise source. To develop the technology for control of noise generation from the electrodes, investigation on the relationship between arc discharge and electromagnetic noise is necessary. 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 electromagnetic noise and trace of discharge on the electrode surface is effective in solving the noise control [3], [4].

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

In this paper, the authors observe the electromagnetic noise and surface change of Ag and Pd contacts.

II. Experimental Method

The schematic diagram of measurement system is shown in Fig. 1. It measures an arc voltage and a noise waveform generated by an opening electric contact. In this measurement, high frequency component of circuit current on the power line is measured with a spectrum analyzer is referred as an index for electromagnetic noise. The noise on the power line is detected by a electric current probe, and measured with a spectrum analyzer(scan width $= 0$[Hz]). Center frequency $f_c = 5$[MHz] is selected in this measurement, because the effect of propagating noise from electric contact on power line is large in range from 3 MHz to 30 MHz [6]. The characteristic of the probe 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 calibration of noise amplitude is not made, and it is referred as a relative value. The measurement of the circuit inductance is 0.7[μH]. This value is so small that there is no effect on the arcing phenomena.

The microphotographs of both electrode surfaces are taken after the first opening operation. The experimental condition is shown in Table I.

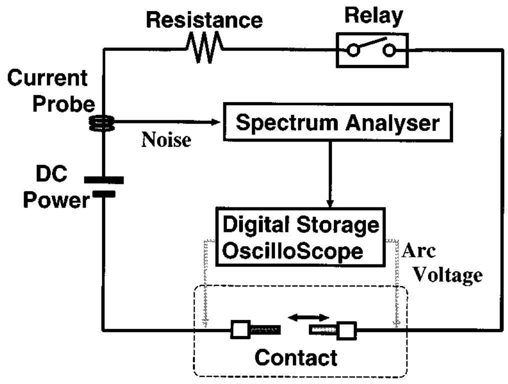

Fig. 1. Schematic diagram of the measurement system.

TABLE I
EXPERIMENTAL CONDITION

Electrode	Ag(1mmϕ), Pd(1mmϕ)
Electrode length	10mm
Circuit voltage	DC10~48V
Circuit current	1~4A
Circuit load	film resistor
Opening speed	40mm/s
Opening number	1 time

III. Experimental Result and Discussion

A. *Overview of Electromagnetic Noise and Change of Surface*

Measurement result at 48[V],4[A] for (a)Ag(anode)-Pd(cathode) and (b)Pd(anode)-Ag(cathode) are shown in Fig. 2. In both current polarities, continuous burst noise(the top) was observed over the whole period of arc discharge. In

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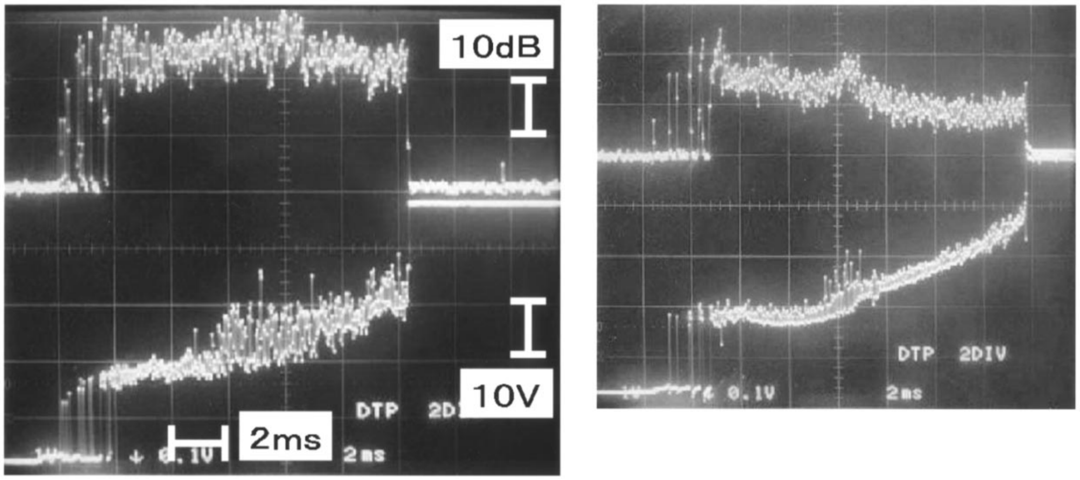


Fig. 2. Noise (the top) and are voltage (the bottom) (a) Ag(anode–Pd(cathode) and (b) Pd(anode)–Ag(cathode).

TABLE II
CLASSIFICATION OF SURFACE AREA

Color	Roughness: rough	Roughness: smooth
Orange	x	a
Blue	x	b
Light brown		c
Black	z	y

TABLE III
OCCURRENCE FREQUENCY OF EACH CASE: AG (ANODE)-PD (CATHODE)

Case	Noise waveform		Feature of surface change							
			Anode(Ag)				Cathode(Pd)			
			x	a	b	z	c	a	b	y
(A)	I	21	21/100%	8/38%	1/5%	0/0%	21/100%	0/0%	0/0%	0/0%
(B)	I+II	26	26/100%	26/100%	26/100%	0/0%	26/100%	0/0%	0/0%	0/0%
(C)	I+II+III	40	4/10%	2/5%	4/10%	36/90%	40/100%	0/0%	0/0%	0/0%
Statistical test on significance			$\chi^2 = 129.6$ $\chi^2(6;0.01) = 16.8$							

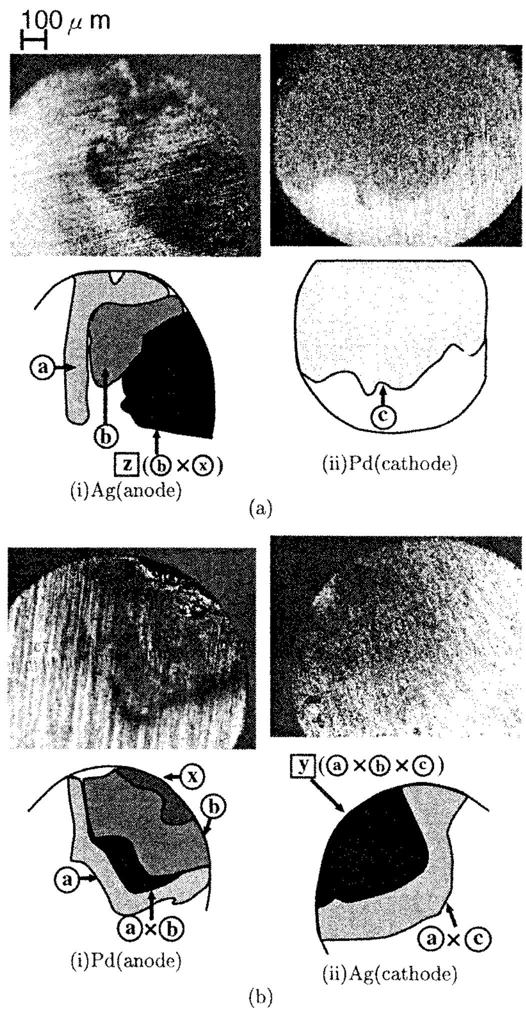
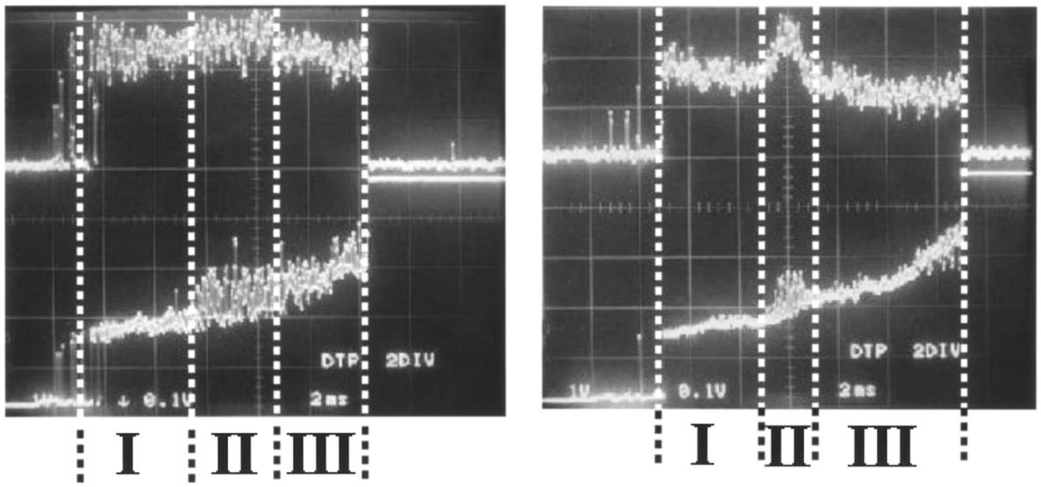


Fig. 3. The microphotograph of electrode surface (a) Ag(anode)–Pd(cathode) and (b) Pd(anode)–Ag(cathode).

the both polarities, the fluctuations of arc voltage(the bottom) are large in the middle part. Macroscopic amplitude of noise is stable in (a), while there is a peak which corresponds to the voltage fluctuation in (b). In both polarities, noise decreases in the later half.

The microphotographs of electrodes for the measurement of Fig. 2 are shown in Fig. 3 along with schematic illustrations. Each area in the illustrations is accompanied with a symbol which denotes for color and view of roughness as shown in Table II. It is considered that the difference of color shows difference of material. The roughness is a macroscopic measurement of microstructure. In this paper, the authors classify areas of surface change by the difference of color and the roughness in microphotographs. Difference of area implies difference of chemical compositions, so that difference of arc discharge phenomena on the surface. Areas of orange and blue are defined as area ⓐ and ⓑ. Area of light brown is defined as area ∘. The areas ⓐ, ⓑ and ⓒ are smooth surface. Rough area is defined as ⓧ. When area ⓧ is mixed with ⓐ or ⓑ,, the area looks black



(a) (b)

Fig. 4. Division of arc voltage and noise periods (a) Ag(anode)–Pd(cathode) and (b) Pd(anode)–Ag(cathode).

TABLE IV
OCCURRENCE FREQUENCY OF EACH CASE: PD (ANODE)-AG (CATHODE)

Case	Noise waveform		Feature of surface change							
			Anode(Pd)				Cathode(Ag)			
			x	a	b	z	c	a	b	y
(A)	I	6	6 / 100%	1 / 17%	0 / 0%	0 / 0%	6 / 100%	0 / 0%	0 / 0%	0 / 0%
(B)	I+II	9	9 / 100%	9 / 100%	9 / 100%	0 / 0%	9 / 100%	1 / 11%	0 / 0%	0 / 0%
(C)	I+II+III	73	44 / 60%	44 / 60%	43 / 59%	29 / 40%	53 / 73%	54 / 74%	19 / 26%	16 / 22%
Statistical test on significance			$\chi^2 = 16.8$, $\chi^2(6;0.01) = 16.8$				$\chi^2 = 18.9$, $\chi^2(6;0.01) = 16.8$			

TABLE V
CLASSIFIABLE PATTERN: AG (ANODE)-PD (CATHODE)

Noise	Surface change	
	Anode(Ag)	Cathode(Pd)
I	x	c
I+II	x a b	c
I+II+III	x a b z	c

TABLE VI
CLASSIFIABLE PATTERN: PD (ANODE)-AG (CATHODE)

Noise	Surface change	
	Anode(Pd)	Cathode(Ag)
I	x	c
I+II	x a b	c
I+II+III	x a b z	a b c y

and is defined as z. On the other hands, black smooth area is mixture of c and areas a or b. This area is defined as y.

In Fig. 3(a)2, areas a and b are observed and area x is mixed with area b on Ag(anode) surface. Area c is distributed widely on the Pd(cathode) surface. In Fig. 3(b), areas a and b are distributed widely on Pd(anode) surface and area x has clear outline and small expanse. Area c is mixed with area a and b on Ag(cathode) surface.

B. Relationship between Electromagnetic Noise Waveform and Change of Surface

In Section III-A, patterns of surface change are classified by surface characteristic. In this section, the authors divide period of arc voltage and noise waveform depending on fluctuation of arc voltage and amplitude of noise. The correlation between the periods and surface change is discussed statistically.

1) Features of Arc Voltage and Noise Waveforms: In Fig. 4, according to the feature of arc voltage waveform, the noise waveform is divided into three periods for (a) Ag(anode)-Pd(cathode) and (b) Pd(anode)-Ag(cathode). The fluctuation of arc voltage is small in period **I**. In period **II**, the fluctuation of arc voltage is large. Macroscopic amplitude of noise in the case of Ag(anode)-Pd(cathode) is stable and become low in period **III**. In the case of Pd(anode)-Ag(cathode), noise is higher in period **II** than other periods.

2) Ag(anode)–Pd(cathode): Observed arc voltage waveforms on several current conditions are shown in Fig. 5. Fig. 5(a)–(c) are for the cases when the waveforms are observed through to periods **I** (circuit voltage = 48[V], circuit current = 1.5[A]), **II** (48[V], 3[A]), and **III** (48[V], 4[A]). These cases are denoted by period **I**, periods **I** + **II**, periods **I** + **II** + **III**, respectively. Occurrence frequency of each area is shown in Table III. Numbers of measurement data are 87.

On Ag(anode) surface, only area x exist in case (A) accompanying a brown material. In case (B), areas a and b are distributed as well as x. It is considered that areas a and b are formed in the period **II**. Similarly, areas a and b are observed in case (C), and area z is distributed widely. By expanding Areas a and b, z is formed in period **III**, and noise decrease at the same time. Chi-square χ^2 of Table III is 129.6, and this result shows the significant correlation at the significance level 1[%].

In Pd(cathode) electrode, only area c exists at all case.

3) Pd(anode)–Ag(cathode): Observed arc voltage waveforms for several current conditions are shown in Fig. 6.

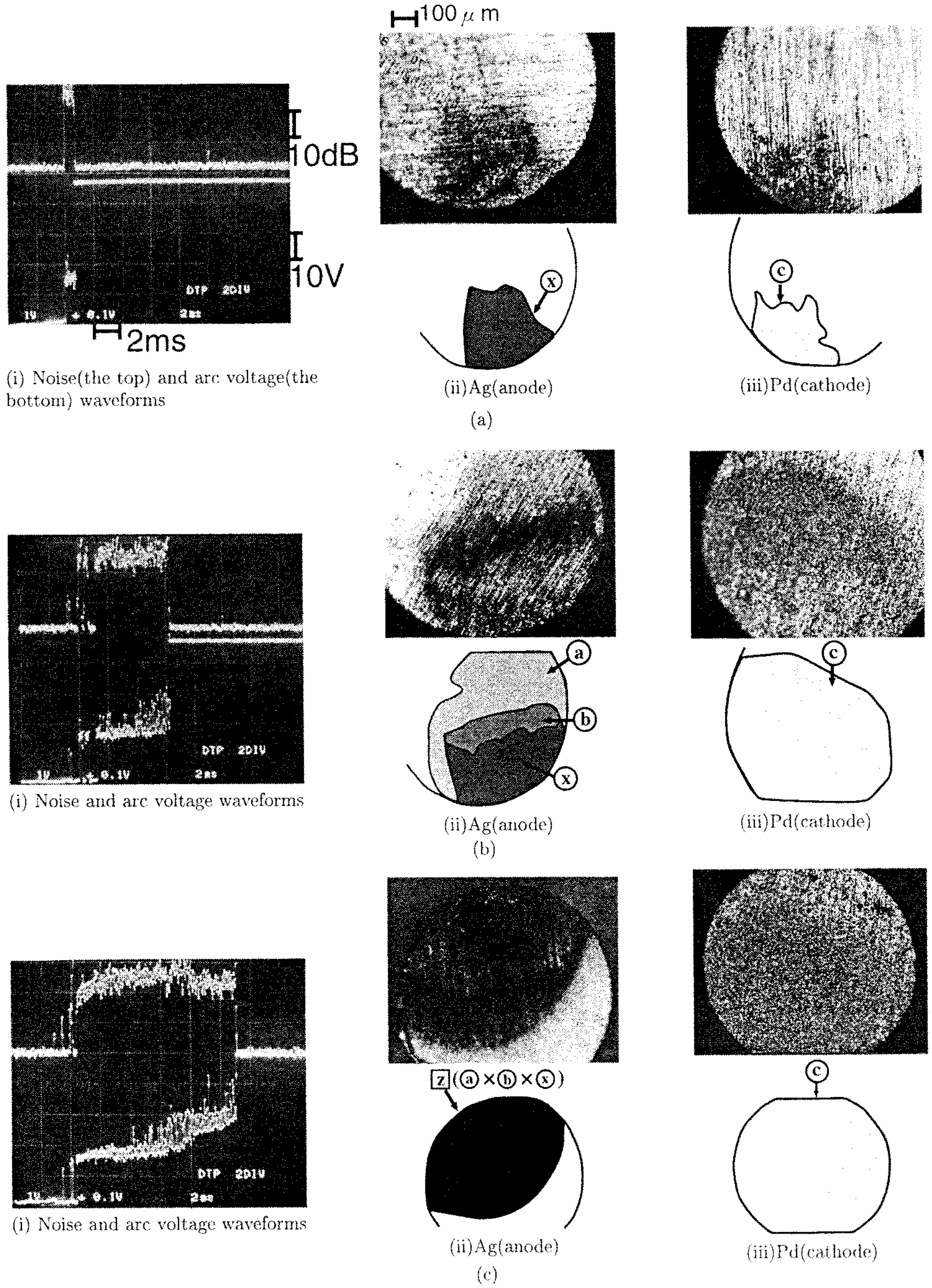


Fig. 5. The examples of each case in Ag(anode)–Pd(cathode) (a) Periods **I**, (b) Periods **I** + **II** and (c) Periods **I** + **II** + **III**.

Fig. 6(a) and (b) are for the cases **I** (48[V], 1.5[A]) and **I** + **II** (48[V], 1.5[A]). Fig. 6(c) is for the case when the arc voltage continues through to the period **III** (48[V], 4[A]). Occurrence frequency of each area are shown in Table IV. Numbers of measurement data are 88.

On Pd(anode) surface, only area x is seen in case (A), and melted parts exist with brown material in this area. In case (B), areas a and b are distributed as well as area x. It is considered that areas a and b are generated in period **II**, and increase of noise during period **II** has relationship with the generation of areas a and b. In case (C), occurrence rate of area $\boxed{z}$ is high. Chi-square χ^2 of Table IV is 16.8, and this result shows the significant correlation at the significance level 1[%].

On Ag(cathode) surface, only area c is seen in cases (A) and (B). In case (C), area c is covered with areas a and b, and area $\boxed{z}$ is formed during period **III**. Noise decreases in the period **III**. Identically with the Ag(anode)-Pd(cathode), it is considered that the generation of noise has relation with the changes of electrode surface, especially generation of area a and b in anode electrode. Chi-square χ^2 of Table IV is 18.9, and this result shows the significant correlation at the significance level 1[%].

4) Distribution of Noise Waveform and Change of Surface at Various Circuit Condition: The distribution of measured noise waveforms and surface changes at various circuit condition are shown in Figs. 7 and 8. Fig. 7 shows the case

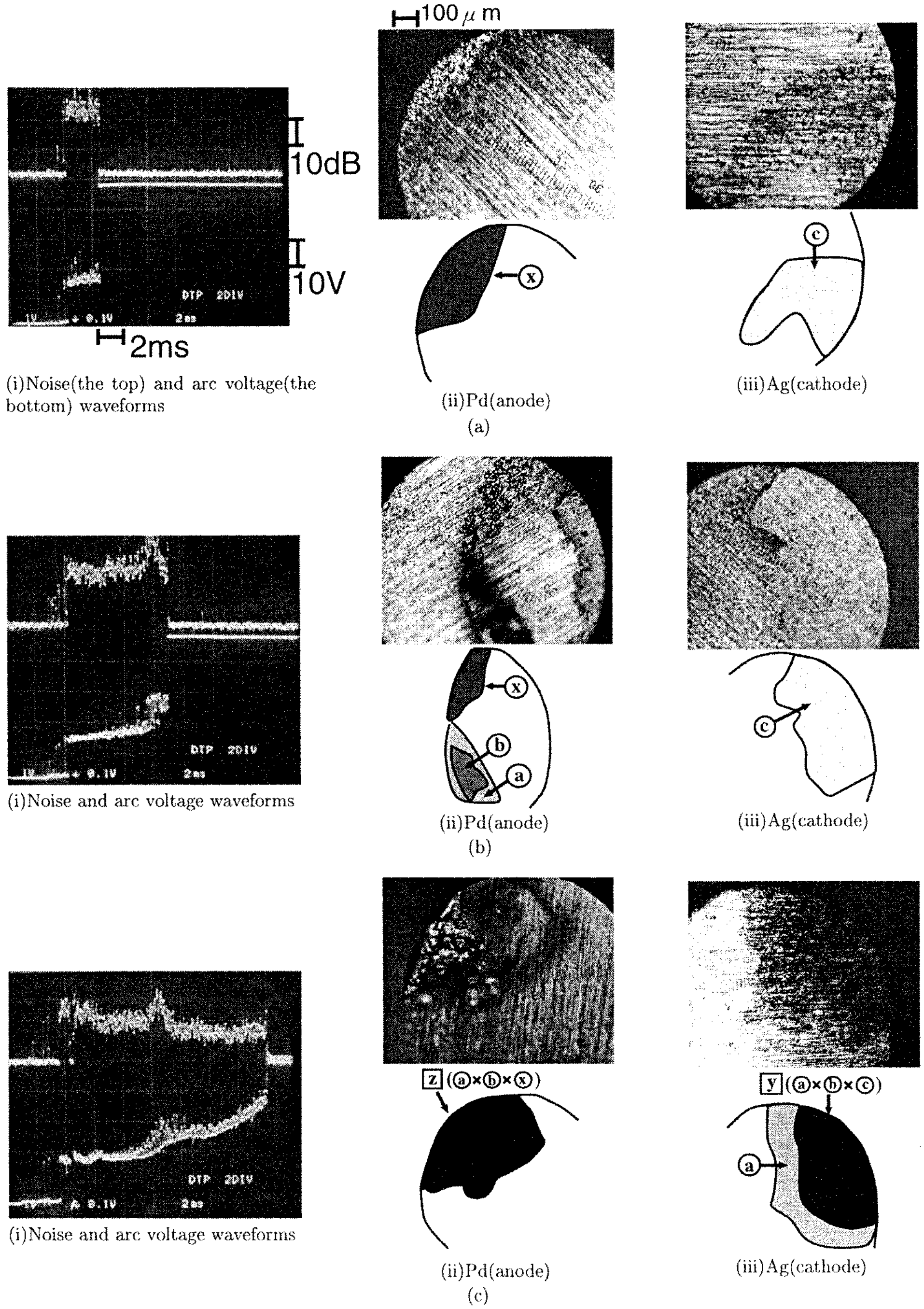


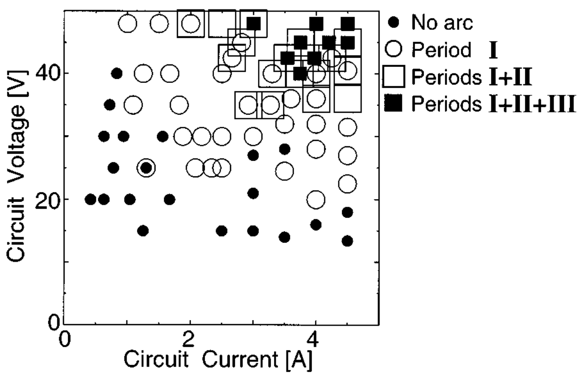
Fig. 6. The examples of each case: Pd(anode)–Ag(cathode) (a) Periods **I**, (b) Periods **I** + *II* and (c) Periods **I** + **II** + **III**.

of Ag(anode)-Pd(cathode) and Fig. 8 shows the case of Pd(anode)-Ag(cathode). Distribution charts (a), (b), (c) of Figs. 7 and 8 show the distribution of noise waveform, anode electrode, and cathode electrode, respectively.

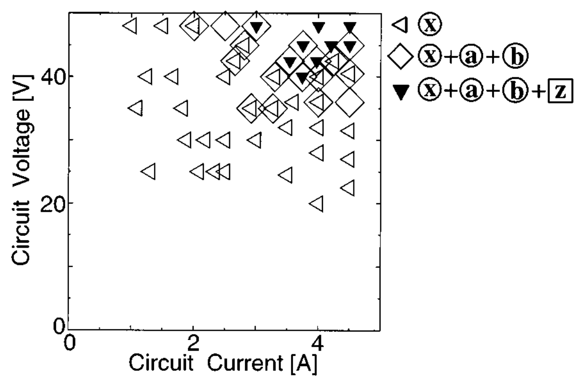
The distribution of noise waveforms show that the higher circuit voltage and current are, the longer noise duration becomes. The periods **II** and **III** are observed when the duration becomes long in the both polarities. Distribution of surface changes corresponds to the results of Tables III and IV. Noise waveform and change of electrode surface are classified into three patterns as shown in Tables V and VI. From these results, the clear correlation between electromagnetic noise and change of surface was shown.

These measurements were repeated for about 90 times in the same condition. Therefore the clear correlation implies the repeatability of these results.

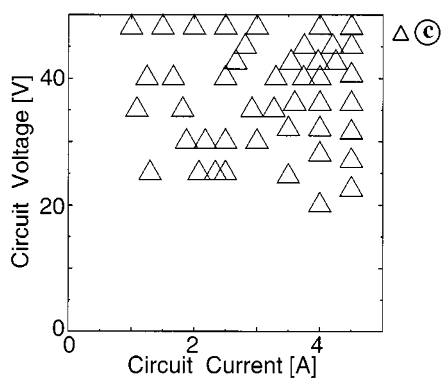
Aida *et al.* presented that the noise reaches a maximum at the Asai's transfer curve [7] for Ag contacts [8]. Sone and Takagi presented about the relationship between material transfer and metallic and gaseous phases of arc [9]. The results of this measurement showed that each period of noise waveform corresponds to the change of electrode surface.



(a)

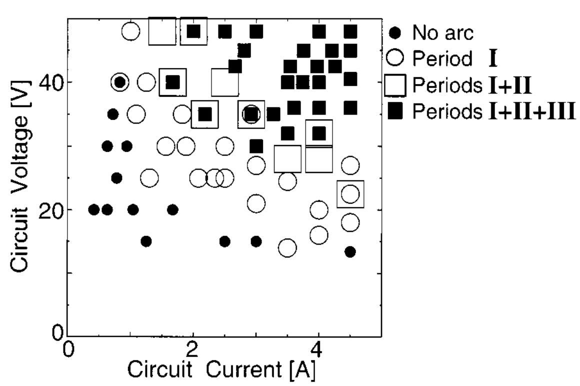


(b)

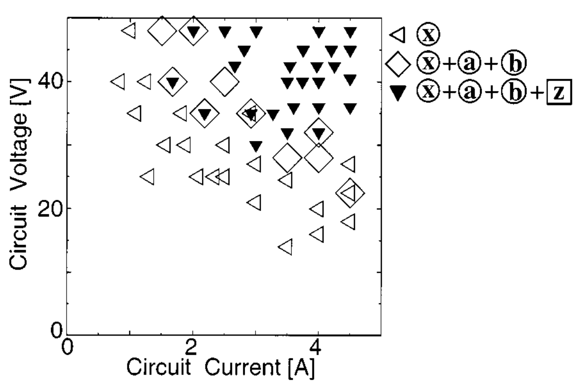


(c)

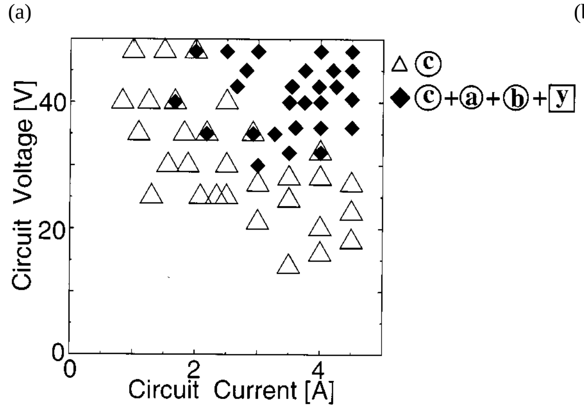
Fig. 7. Distribution of noise waveform and change of surface at various circuit condition in Ag(anode)–Pd(cathode) (a) Noise waveform, (b) Anode(Ag) and (c) Cathode(Pd).



(a)



(b)



(c)

Fig. 8. Distribution of noise waveform and change of surface at various circuit condition in Pd(anode)–Ag(cathode) (a) Noise waveform, (b) Anode(Pd) and (c) Cathode(Ag).

As these results, the authors showed the correlation between occurrence pattern of noise and the change of electrode surface.

IV. CONCLUSION

The authors observed the relationship between electromagnetic noise and the change of surface for arc discharge of opening Ag-Pd contacts. The measurement is a fundamental study on action of electromagnetic noise from electric contacts in small electric appliances. The following findings have been obtained from the experimental result.

In case of Ag-Pd electrodes, a continuous noise generates over the whole period of arc discharge in both current polarities. The fluctuation of arc voltage is large in the second period (**II**), then the noise is large. The noise decreases in the third period (**III**).

The authors proposed a classification of noise waveforms and pattern of surface changes. Arc voltage and noise waveform are divided into three periods depending on the fluctuation of arc voltage and amplitude of noise. Areas of surface change are classified by the difference of color and the roughness on electrode surface. As these results, noise waveforms and changes of electrode surface at various circuit conditions are classified into three categories. In this paper, the authors showed the correlation between the occurrence pattern of noise and the change of electrode surface.

It is a future problem to develop a way to reduce or eliminate EMI, and the control of noise generation can be enabled by making clear the mechanism of increase of noise in the second period (**II**) mentioned above. The authors demonstrated an investigation of the condition of the specific surface changes in connection with generation of large electromagnetic noise, it may be a new approach of noise control technology.

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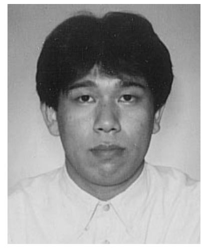

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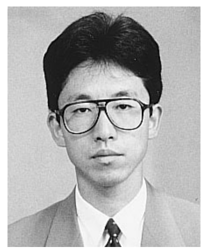

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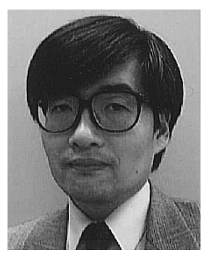

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