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# Degradation Phenomenon of Electrical Contacts by using a Micro-Sliding Mechanism –Modeling about Fluctuation of Contact Resistance –

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**Abstract–** Authors have developed some mechanisms which give real vibration to electrical contacts and studied the influences of a micro-oscillating on the contact resistance. By using the mechanism, "Micro-Sliding Mechanism II", which is developed on trial, they obtain time-sequential fluctuation data of contact voltage. It is shown that there are quasi-stable and periodic closed orbits and bifurcation-like phenomenon in the data by using phase plane analysis. It is indicated that the data are able to be simulated by higher and lower frequency simple rectangular wave. It is also shown that there are stable and periodic closed orbits and bifurcation-like phenomena similar to the above and that there are different phenomena from the above. It is suggested that there is necessary to consider the non-linearity in the system for analyzing the difference caused the fluctuation of amplitudes or frequencies and data jumping.

## 1. Introduction

It is a primary consideration in connector designs that a serious failure mechanism is in the contact systems. Electrical contacts have been widely applied to mobile equipment, car electronics, communication network systems, etc. Once the failure in the contact system occurs, it is clear that many systems in the world will be widely paralyzed. Therefore, it is extremely important to secure the confidence and the safety of the electrical contacts.

Concerning a testing or an examination on the electrical contacts under the influence of external vibrations, there are already so many methods or protocols. They are, however, almost only more general and less detailed methods or procedures for measuring signal-to-noise ratio using free-fall of a ball or they are made by the method for measuring influences by external representative sinusoidal waves. They are not always adjusted to the examination in general circumstance where electrical devices are used [1].

Authors have developed the mechanisms which give damping vibration to electrical contacts by reciprocal hammering oscillation and by periodical micro-sliding to electrical contacts. It is shown that each mechanism is able to make a test simulate an actual degradation phenomenon on electrical contacts under the influence of micro-oscillation [2].

Micro-sliding mechanisms, which have be studied and developed for a long time [3], have recently explain the relationship the degradation mechanism and the relative displacement & contact load between two materials. Especially most recent studies show the minimal sliding amplitude and contact load by experimental data or computational simulations [4].

It is, however, not enough to explain what processes are in the degradation phenomenon of electrical contacts by only the above. Especially, contact resistance fluctuation in time-sequential data is too complex to explain the phenomenon by usual linear analysis.

In this paper the authors try to analyze the phenomenon by non-linear theory and its applications [5]. They obtain that there are quasi-stable and periodic closed orbits and bifurcation-like phenomena in the data by using phase plane analysis.

It is indicated that the experimental data are able to be simulated by larger and smaller simple rectangular waves. It is also shown that there are stable and periodic closed orbits and bifurcation-like phenomena similar to the above by using phase plane analysis and that there are different phenomena from the above.

It is suggested that there is necessary to consider the non-linearity in the system for analyzing the difference caused the fluctuation of amplitudes or frequencies and data jumping although the phenomena depend upon the non-linearity of the inputs into the system.

## 2. Oscillating mechanisms

The authors have developed some oscillating mechanisms, for example, "Hammering Oscillating Mechanism (HOM) [5]", "Micro-Sliding Mechanism 1(MSM1) [4]," and "Tapping Device (TPD) [2]". Using the mechanisms they have studied the degradation phenomenon of electrical contacts [5].

### 2.1. Micro-Sliding Mechanism 2 (MSM2)

Although the HOM is very simple and strong mechanism, it provides only an impulsive load to objects in the vertical direction only. Although the TPD is very handy and lower priced, it is not suitable for many operations. And although MSM1 provides very precise sliding motions to objects according to the optional input signals, there is thermal drift in the magnetostrictive actuator and the system is very expensive.

The authors have developed a new mechanism, such as "Micro-Sliding Mechanism 2 (MSM2)" which provides more precise sliding motions and less thermal drift and a relatively lower price. The system is compounded from four elastic hinges which are symmetrical with respect to a point and a line to one another and a Piezo-electric actuator (Fig.1). The sliding displacement is measured by a capacitance sensor. The sliding displacement occurs between male-pins and female-parts in a common connector when the actuator is drive by a function generator (±5.0V) and amplifier circuits (×20).

### 2.2. Fundamental performance of MSM2

The performance of the mechanism is measured in the translational and rotational directions when the actuator is driven in the horizontal direction (y-direction) with rectangular input waveform (Fig.2). A, B, C, D and E are measured points by the capacitance sensor.

"Z" is displacement in the z-direction at the time in Fig.3. Although the data in the z-direction have the influences of rectangular oscillations, they show that the mechanism transfers the input signals to the displacements in the y-direction accurately. "θz", "θy" and "θx" show rotations around z-, y- and x-direction respectively. Because the data of rotations are small, it is illustrated that the interferences among the directions are smaller than 10%.

## 3. Experiment on electrical contact with MSM2

The Micro-Sliding Mechanism 2 is slid between male-pins and female-parts in the sample connector attached on the stage of the mechanism with 10 couples of pin made from tin plated copper compound (HOROSE-DF1B). Frictional force between a male-pin and a female-part is 0.3N/pin. Sliding amplitude is ±2.4µm. Input waveform is rectangular at a frequency of 4.0 Hz. Current running through daisy-chained pins in a connector is 10.0mA. Data sampling frequency is 100Hz. Fig.4 shows the voltage fluctuation in the above condition. At 65,000 seconds from the beginning the voltage begins to fluctuate and the fluctuation is clear from 70,000 seconds.

## 4. Results

Using 32,000 data at about 80,000 seconds from the beginning (red line in Fig.4), (1)raw data, (2)data after 5-points moving average, (3)data after 10-points moving average, (4)data after 15-points moving average, (5)data after 20-points moving average and (6)data after 25-points moving average are shown in Fig.5. It is illustrated that there are higher frequency waves in relation to input waveform (4.0Hz) and lower frequency ones (about 0.015Hz) in relation to something about degradation phenomenon on electrical contacts in Fig.5.

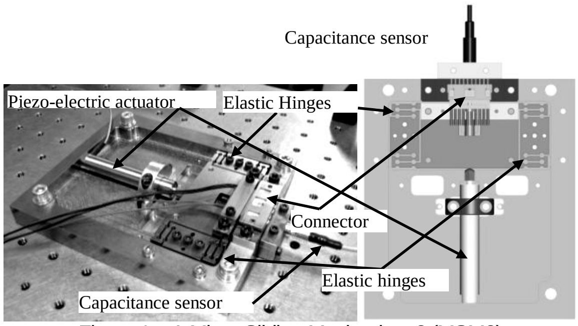

Figure 1 A Micro-Sliding Mechanism 2 (MSM2).

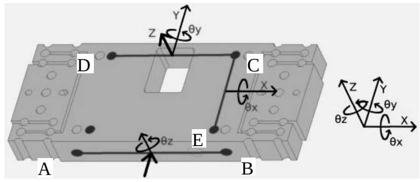

Figure 2 Arrangements of sensors for measuring the displacements.

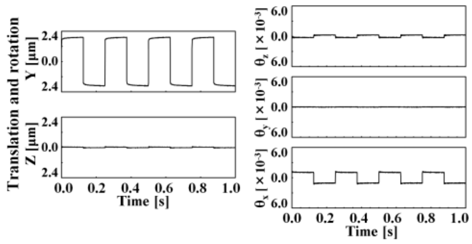

Figure 3 Displacements in z, $\theta_x$, $\theta_y$ and $\theta_z$ directions when the actuator is driven in the y-direction.

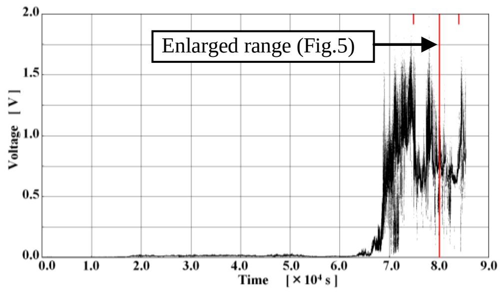

Figure 4 Voltage fluctuation in the condition of frictional force of 0.3N/pin, 10pins connected in series, rectangular input and sliding amplitude of ±2.4µm.

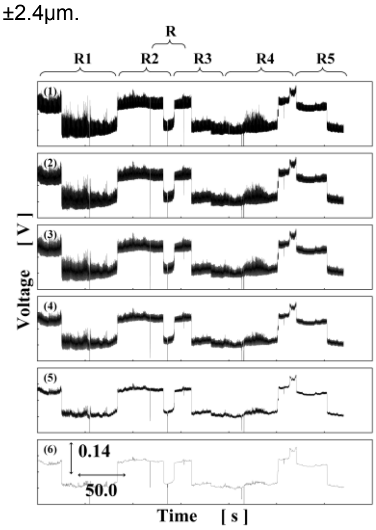

Figure 5 Fluctuation of voltage in the enlarged range of the line (Fig.4).

## 5. Discussions

### 5.1. Moving averaging processing and phase plane analysis

Phase planes are drawn using time-sequential fluctuation data in Fig.5-1, 5-2, 5-3, 5-4, 5-5 and 5-6. $V(t_i)$s v.s. $V(t_{i+1})$s are illustrated in Fig.6 and $V(t_i)$s v.s. $(V(t_i)-V(t_{i-1}))/(t_i-t_{i-1})$s are illustrated in Fig.7. In other words, figures in first row in Fig.6 and Fig.7 show first ranges named R1 in Fig.5, figures in second row show second ranges named R2, figures in third row show third ranges named R3, figures in the fourth row show the forth ranges named R4 and figures in the fifth row show the fifth ranges named R5. Namely, figures in first column show Fig.5-1, figures in second column show Fig.5-2, figures in third column show Fig.5-3, figures in the fourth column show Fig.5-4, figures in fifth column show Fig.5-5 and figures in sixth column show Fig.5-6.

It is indicated that each figure in first column (raw data) in Fig.6 has closed orbits and bifurcation-like phenomena. On the other hand, the larger the averaging numbers are the more oblate the orbits are. It is suggested that there is major effect of the averaging in the figures. It is, however illustrated that there are bifurcation-like phenomena in all figures. It is also indicated that all figures have bifurcation-like phenomena and all figures except those in the sixth column in Fig.7 have closed orbits. It is suggested that there is minor effect of the averaging in the figures.

Higher-frequency elements disappear comparatively early and lower-frequency ones remain comparatively late according as the averaging numbers increase in Fig.6 like Fig.5. On the other hand, not only higher-frequency elements but also lower-frequency ones remain comparatively late in Fig.7. The authors consider that the bifurcation-like phenomena in Fig.6 and Fig.7 remain after averaging because the phenomenon is in relation to degradation phenomenon of electrical contacts and the closed orbits in Fig.7 remain after averaging because the dV/dt is rate of rectangular wave [6].

### 5.2. Analysis by simple waves

Fig.8 (left) illustrates fluctuation of voltage in the enlarged range of the region “R” in Fig.5-1. It is shown that the waves are almost composed of higher-frequency waves and lower-frequency ones extracted from Fig.5. It is, however also shown that not only the frequency but also amplitude are not constant and that there are jumping data different from other ones.

Fig.8 (right) illustrates fluctuation of voltage simulating Fig.8 (left). The wave is composed of a high-frequency wave (4.0 Hz) and a low-frequency one (1/64 Hz). Using the data, Fig.9-1 is illustrated in the same range (32,000data, 320seconds) in Fig.5. By the same averaging, Fig. 9-2, -3, -4, -5 and -6 are drawn. It is shown that the tendency of the data is similar to Fig.5. Using waves in the range R1 in each case, phase plane figure are drawn (Fig.10).

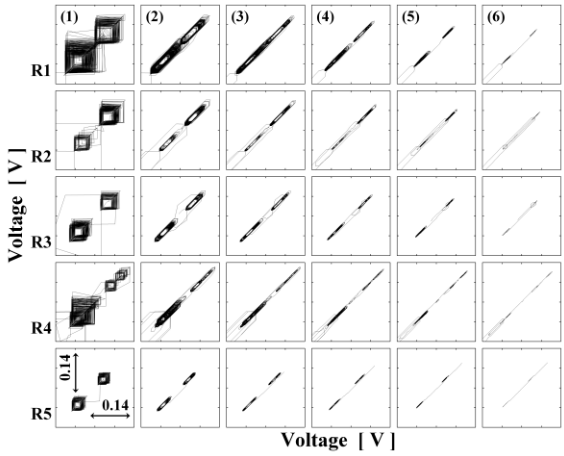


Figure 6　Phase plane analysis using $V(t_i)$ v.s. $V(t_{i+1})$ in five ranges of Fig.5.

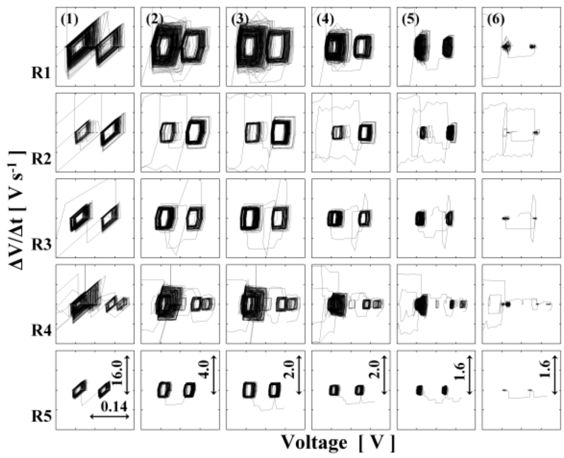


Figure 7　Phase plane analysis using $V(t_i)$ v.s. ΔV/Δt in five ranges of Fig.5.

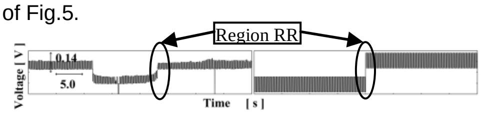


Figure 8　Fluctuation of voltage in the enlarged range of the region “R” in Fig.5-1 and fluctuation of voltage simulating the figure(left) with 2 types (higher and lower) of rectangular wave (Fig.8 right).(See §5.3.1 about Region RR )

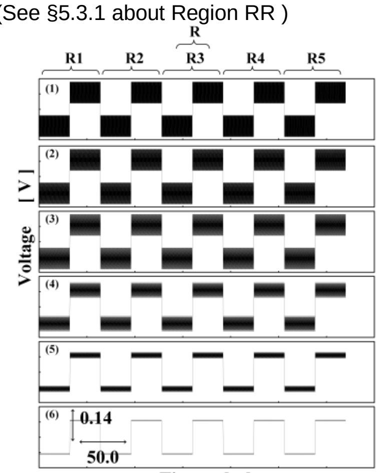


Figure 9　Fluctuation of voltage simulated by two types of rectangular wave in the same range of Fig.5.

Fig.10 (upper) shows $V(t_i)$s v.s. $V(t_{i+1})$s and Fig.10 (lower) shows $V(t_i)$s v.s. $(V(t_i)-V(t_{i-1}))/(t_i- t_{i-1})$s. Higher-frequency elements disappear comparatively early and lower-frequency ones remain comparatively late in in Fig.10 (upper). On the other hand, not only higher-frequency elements but also lower-frequency ones remain comparatively late in Fig.10 (lower).

The authors consider that the bifurcation-like phenomena are concerned with in lower-frequency waveform, which is caused by degradation phenomenon of electrical contacts, and the closed orbits are concerned with high frequency waveform, which is caused by input displacement of the mechanism.

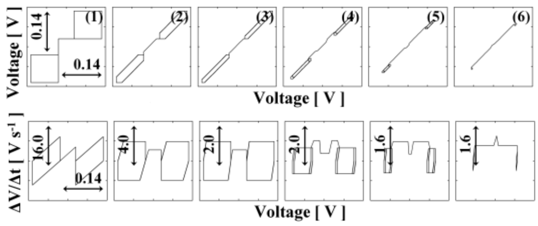


Figure 10 Phase plane analysis using $V(t_i)$ v.s. $V(t_{i+1})$ and $V(t_i)$ v.s. $\Delta V/\Delta t$ in the range R1 in Fig.9.

## 5.3. Closed orbits and bifurcation-like phenomena

### *5.3.1. Similarities between experimental results and simple ones in phase plane analysis*

The authors consider that there are similarities that each figure has two closed orbits and two orbits are connected to each other with the help of some points between two orbits in Fig.6, Fig.7 and Fig.10. The orbits and points do not draw a figure of "8". After points are going around one orbit in a term, they move into the area between two orbits and go around another orbit in the next term.

Fig.11 or Fig.12 illustrates time-sequential voltage fluctuation (in the left figure), V-V phase plane (in the middle figure) and V-$\Delta V/\Delta t$ phase plane (in the right figure) using experimental or simple waves respectively (from Fig.8: Region RR).

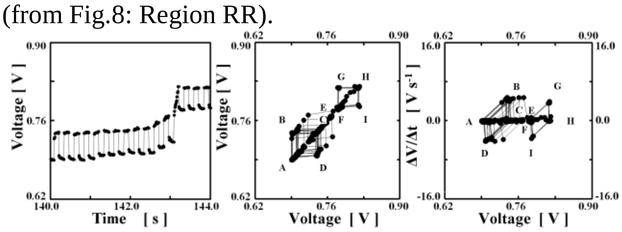


Figure 11 Closed orbits and bifurcation-like phenomena in time-sequential fluctuation and phase plane analysis by experimental waves.

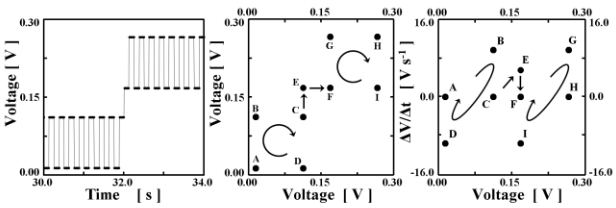


Figure 12 Closed orbits and bifurcation-like phenomena in time-sequential fluctuation and phase plane analysis by simple waves.

It is shown in Fig.11 (in Fig.12) that there are 11 points are on A, some points one point is on B, 11 points are on C and one point is on D according to the course of time. After points go around the ABCD-orbit at 12 times (8 times) clockwise, points move into E. It is also shown in Fig.11 (in Fig.12) that there are 11 points are on F, one point is on G, 11 points are on H and one point is on I according to the course of time. After points go around the EFGH-orbit at 4 times (8 times) clockwise, points move into E.

The authors consider that there are parallels between the figures by experimental data (in Fig.11) and those by simple waves (in Fig.12). Therefor it is suggested that the closed orbits and bifurcation-like phenomena depend on the nonlinearity derived from the input signal (as higher-frequency waves) and from the system (as lower-frequency waves).

### *5.3.2. Differences between experimental results and simple ones in phase plane analysis*

On the other hand, the authors consider that there are differences between experimental waves and simple ones. It is indicated that there are fluctuations, which are not periodic, on not only periods but also amplitudes in both higher-frequency and lower-frequency wave in experimental data. In addition, it is shown that there are jumping and discontinuous data about experimental waves.

It is illustrated that there are many orbits which vary in size and in shape and more bifurcation-like phenomena than two. It is suggested that there is non-linearity in the system, because the output is contact voltage, although the mechanism slides regularly in displacement.

## 6. Conclusions

Authors have developed a new mechanisms "Micro-Sliding Mechanism II". They obtain time-sequential fluctuation data of contact voltage. It is shown that there are quasi-stable and periodic closed orbits and bifurcation-like phenomena in the data by using phase plane analysis.

It is indicated that the data are able to be simulated by higher- and lower-frequency simple rectangular wave. It is also shown that there are stable and periodic closed orbits and bifurcation-like phenomena similar to the above and that there are different phenomena from the above.

## References

[1] JEITA, "Test methods for solder joint of surface mount device Part107", *JEITA ET-7409-107*, 2010

[2] Wada, S. and Sawa, K., *Proc. 57th IEEE Holm Conf. on Electrical Contacts*, pp.309-316, 2011

[3] Bouzere, A. et al., *Proc. 25th Int. Conf. on Electrical Contacts (ICEC) and 56th IEEE Holm Conf. on Electrical Contacts*, pp.101-107, 2010

[4] Wada, S. and Sawa, K., Proc. *58th IEEE Holm Conf. on Electrical Contacts*, pp.147-154, Spt., 2012

[5] Wada, S. and Sawa, K., *IEICE Transactions Communication*, printing

[6] Strogatz, S. H. *"Nonlinear dynamics and chaos"*, Perseus Books Publishing, December, 1994