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Arc Tracking Between Space Cables due to Electrostatic Discharge

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Discharge mechanism in a space-used cable is needed to clarify the arc tracking formation process on the cable under different environments, against the background of the accident of ADEOS2. The experiment was performed in the vacuum chamber that simulated LEO environment. Three types of sample cables were prepared under different environments (Cut, Heat and UV). Arc tracking formation process has been studied by repetition of sustained arc (SA) inception. With the repetition of SA inception lowering of the resistance between the cables was observed. Only the arcs tracking which occurred below the resistance of about 10kΩ were studied. As a result, there was no difference observed between the cables prepared under different environments. Arc tracking formation process does not depend on the state of deterioration of cable.

Key Words: Cable, Discharge, Arc tracking

1. Background

There was an accident due to power fall down from 6K W to 1K W on an environmental observation technical satellite ADEOS2 in October 2003 during passing through auroral-zone. The accident[1] was caused by a discharge in the electric power transmission cable which connected a solar array paddle to a satellite body. This discharge is called sustained arc[2] (SA).The sustained arc is accompanied by a local heating. The insulated skin film of a cable was burned and carbonized. The carbonizing part is called arc tracking. This arc tracking between cables causes short-circuit of the power cable. Therefore, the short-circuited cables are unable to supply power to the main body of the satellite. The study of the discharge mechanism in a space-used cable has been done against the background of the accident of ADEOS2. However, almost all the research was done on the cables inside the satellite. SA can occur anywhere if potential different part is adjacent. Therefore, it is necessary to study the electrical discharge phenomenon in cables on the various parts of satellite. The purpose of this research is to clarify the arc tracking formation process on different cables exposed to various environments. This research will contribute to design the cables for future satellite in order to prevent the accident like ADEOS2.

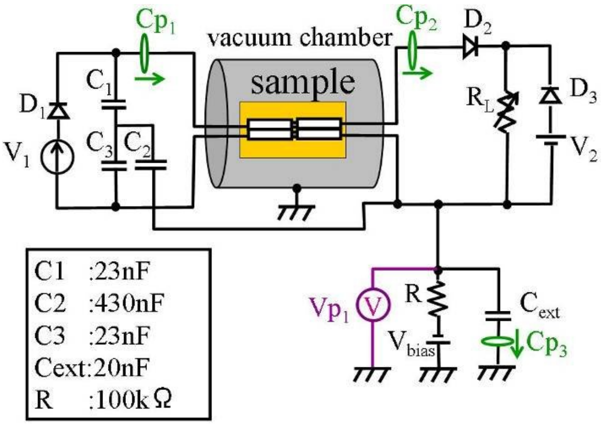
2. Research Method

Cracks are formed on a cable due to a heat cycle, or degradation by ultraviolet rays. This crack forms triple junctions at the interface of conductive part of cable core, insulated cable skin film and space plasma. A primary discharge is occurred in the triple junction and causes to form discharge plasma adjacent to it.

If a primary discharge occurs in an adjacent crack of the cables, the discharge plasma may cause the short-circuited of the adjacent cables with a potential difference. As a result, the discharge current between the cables continue flowing. This discharge is called sustained arc (SA).

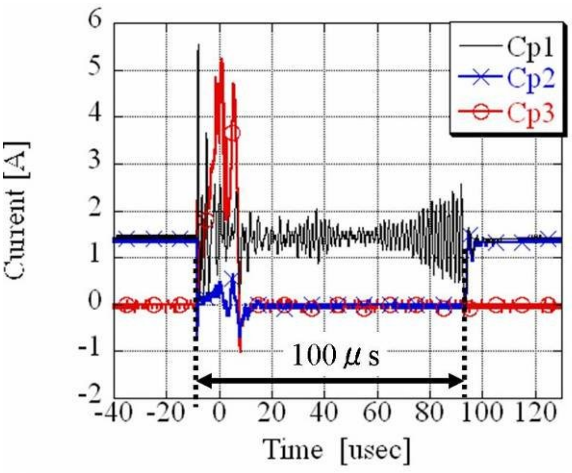
This experiment was completed in a vacuum chamber simulating a low earth orbit (LEO) environment. The pressure in the chamber during the experiment was about 1×10^{-3} Pa. The plasma density was about 1×10^{12} m^{-3}. The current and voltage between lines are 1.5 A and 100 V, respectively.

Figure 1 shows the experimental circuit and the measurement points of voltage (Vp) and current (Cp). This circuit ensures the power generation of the satellite. In Fig, 1, V1 was operated by constant current mode (CC). V2 was operated by constant voltage mode (CV). V1 and V2 simulate the power generation of the solar array. The capacitance C1, C2, and C3 simulate a capacitance of solar array circuit [3]. In the experiment, we simulated the capacitance of a solar array equivalent to the 200 silicon solar cells connected in series (electricity generated by a unit cell was 0.5 V). The R_L imitated the load of satellite body. The V_{bias} was the potential difference between the surrounding plasma and the satellite body. The energy of the primary discharge was measured from the C_{ext}.



Fig, 1 Experimental circuit

Figure 2 shows the typical waveform of SA detected at three points. The current value subtracted from Cp2 to Cp1 is the arc current flowing between cables. We can understand that this SA continued for 100 μs. The resistance between the cables was measured repeatedly during the experiment to investigate the arc tracking and sustained arcs.



Fig, 2 Typical waveform of sustained arc

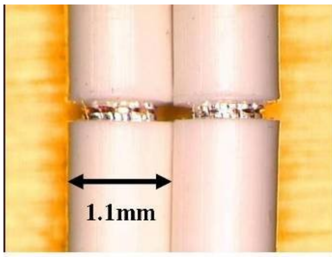
3. Experimental Sample

The SPEC55 (Raychem, Co) was used as the sample cable for this experiment. This cable has been using over 15 years in an industrial field in space. The ADEOS2 also used a similar cable as an electric power transmission. The diameter of the cable is about 1.1 mm (include the film), and the thickness of the insulation film is 0.15 mm. Since the exposure of the cable core was necessary for the inception of discharge, the cable was cracked. The aluminum plate was used as the substrate upon which sample cables were set and insulated by the polyimide tape.

Three kinds of samples have been chosen in the experiment as follow.

- **Virgin Sample (Cut)**

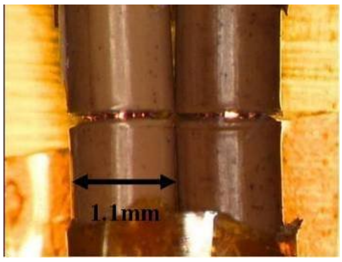
To make a Cut sample, two cable films were cracked and adjoined together shown in the Fig, 3.



Fig, 3 Photograph of Cut sample.

- **Heat Sample (Heat)**

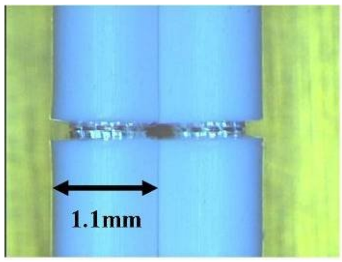
A Heat sample was produced by heating the cable at 260 °C for 71.5 hours followed by cracking and adjoining together shown in Fig, 4.



Fig, 4 Heat sample

- **UV Sample (UV)**

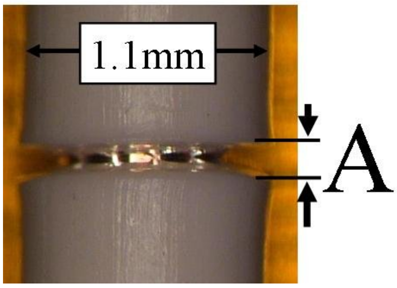
To prepare a UV sample, the cables were cracked and irradiated with ultraviolet rays for 1000 ESH (Equivalent Sun Hours) followed by adjoining together. The UV sample corresponds to the cable exposed to ultraviolet rays in space for 1000 hours (Fig, 5).



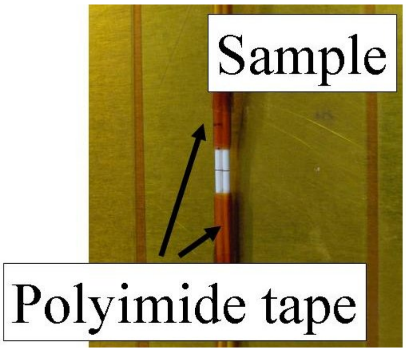
Fig, 5 UV sample

In order to reduce the discreteness of the experimental result all the crack shapes and sizes were produced in an identical technique.

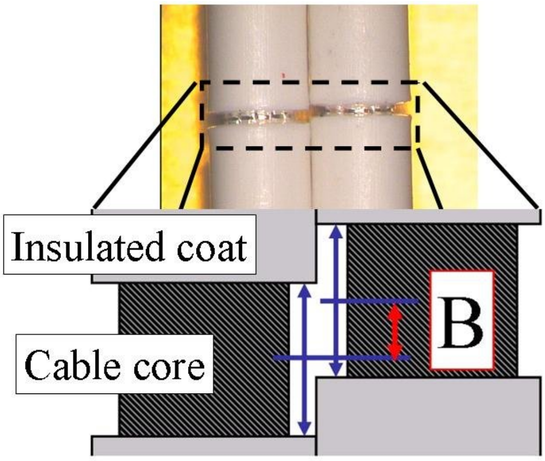
100 samples have been selected to determine the error margin of peripheral distance between the insulated coats after being cut (A in Fig, 6). On the other hand, 23 samples (one is shown in Fig, 7) have been chosen to calculate the error margin of the displacement distance, B, shown is Fig, 8. Here, B is the distance measured from the centers of cable core of two adjacent cables. The mean and standard deviation of A and B are shown in Table 1.



Fig, 6 Sample after insulation of the cable being cut.



Fig, 7 Two adjacent cables taped by polyimide.

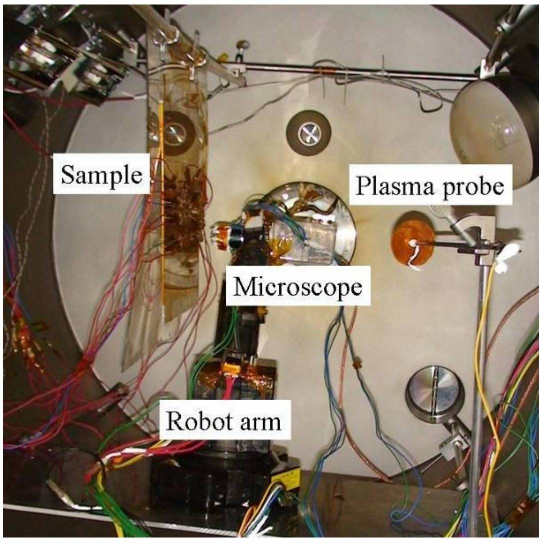


Fig, 8 Closer view of two adjacent cables

Table, 1 :Average and Standard Deviation of A and B

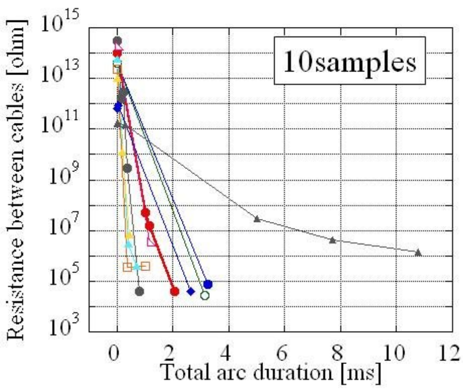
Measure point	Average and standard deviation
A	0.16± 0.02 [mm]
B	29± 24 [μ m]

4. Arc Tracking

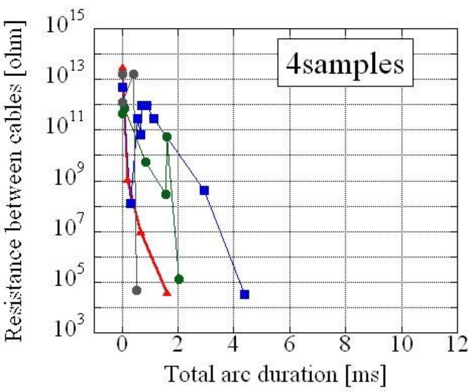


Fig, 9 Overall view of experimental device

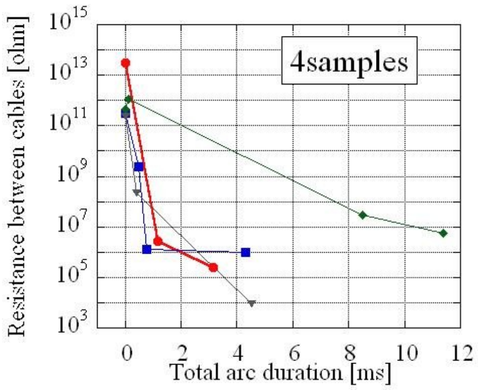
Figures 10, 11, and 12 show the relation between the resistances measured in various cables and total arc duration. X axis shows an accumulation of the duration of SA, while Y axis shows the resistance between the cables. Although, the shape and sizes of the cable cracks were identical, there might be individual differences that may cause error margins during adjoining the cracked cables.



Fig, 10 Cut sample resistance vs total arc duration



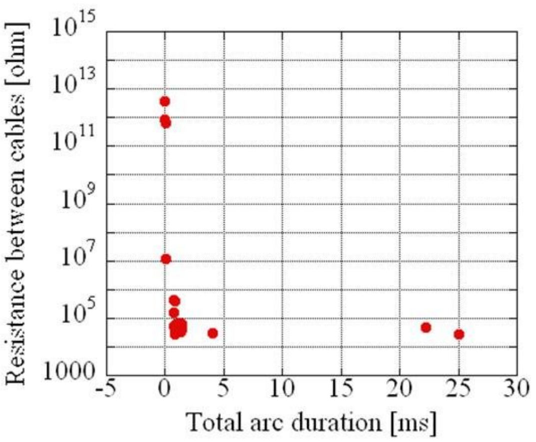
Fig, 11 Heat sample resistance vs total arc duration



Fig, 12 UV sample resistance vs total arc duration

From Figs, 10, 11, and 12, it is concluded that the arc tracking occurred while accumulations of SA duration and by the repetition of SA, resistances between the cables were reduced. From Fig 10, it was confirmed that the resistance decreased to 10kΩ caused by the accumulation of the SA duration for the first 400 μs. From Fig, 11, three samples among four showed recovered resistance. The reason for recovered resistance is due to peeling off the arc tracking formed between cables by repeating the primary discharge and SA.

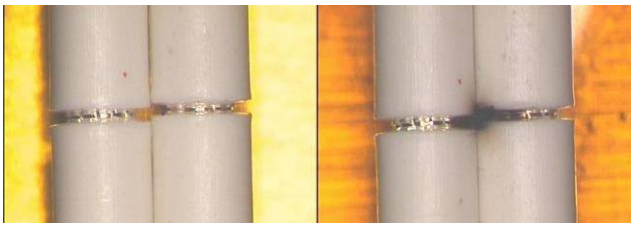
The experiment was performed to find how much the resistance between the lines of virgin sample decreased by accumulating SA duration. Figure 13 shows a relation between cut sample resistance and total arc duration.



Fig, 13 Cut sample resistance vs total arc duration

From Fig, 13, SA duration has accumulated up to 25 ms. About 250 secondary arcs were counted in 25 ms. However, the resistance between the cables has decreased only to about 10kΩ. The photograph of the sample before and after the arc tracking is shown in Fig, 14.

There was not enough energy to melt the cable core in a single repetition of SA and hence, only the cable film was carbonized. Therefore, it is thought that the resistance did not decrease below 10K Ω.



Fig, 14 Test before and after. (Resistance :10K Ω)

5. Comparison of sample

The total arc duration at which the resistance between the cables reduced to less than 10M Ω were compared for each sample. Table 2 shows the average and standard deviation for total arc duration. From this Table 2, we can understand that for each sample (Cut, Heat, UV), their standard deviation is large compared with their average. It may be concluded that there is no difference between each sample (Cut, Heat, UV) for the total arc duration while the resistance is less than 10M Ω. So, it is summarized that the arc tracking formation process does not depend on the state of deterioration of the sample.

Similarly, Table 3 shows the average and standard deviation for SA duration. From Table 3, we can understand that for every sample (Cut, Heat, UV) their standard deviation was large compared with their average. So we can say that there was no difference between each sample (Cut, Heat, UV) for SA duration. We can understand that SA duration does not depend on the state of deterioration of the sample.

Table, 2 :Average and Standard Deviation of total arc duration that became less than 10M Ω

Sample	Average and Standard Deviation
Cut	1.8± 2.2 [ms]
Heat	0.8± 0.7 [ms]
UV	3.4± 4.4 [ms]

Table, 3 :Average and Standard Deviation of SA duration

Sample	Average and Standard Deviation
Cut	73± 169 [μs]
Heat	69± 77 [μs]
UV	93± 149 [μs]

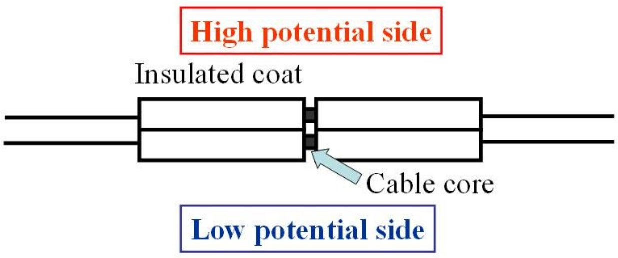
6. Summary

In each sample (Cut, Heat, UV), we could obtain the decrease the resistance between cables due to repetition of SA inception. Only the arc tracking of about 10K Ω was formed by repeating a single inception of SA.

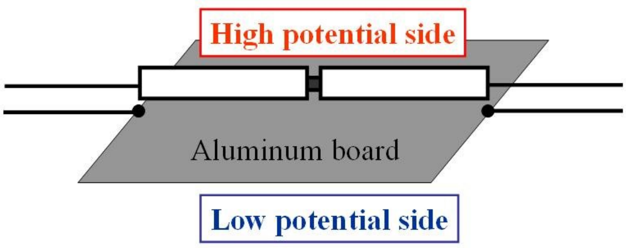
The total SA duration less than 10M Ω were compared between samples (Cut, Heat, UV) and found no difference. There was also no difference in SA duration between samples (Cut, Heat, UV). It is also summarized that the arc tracking formation process and SA duration does not depend on the state of deterioration of the sample. This research will contribute to design the cables for future satellite in order to prevent the accident like ADEOS2.

7. Future Tasks

All the crack shape and size was made identical for the experiment to reduce the error in the result. However, in Tables 2 and 3, the standard deviation is large compared with the average. This time, the cable was placed both in the low as well as high potential side as shown in the Fig, 15. In future, an aluminum board will be positioned in the low potential side, and cable will be used in the high potential side as shown in Fig, 16. In this arrangement error margin could be avoidable which occurred when two cables were adjacent. Moreover, we need to unify all the cables including the samples used in this system.



Fig, 15 Figure of the sample



Fig, 16 Figure of the new sample

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