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Hypervelocity Impact Induced Arcing and Kapton Pyrolization in a Plasma Environment

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HYPERVELOCITY IMPACT INDUCED ARCING AND KAPTON PYROLIZATION IN A PLASMA ENVIRONMENT

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Abstract

Tests were performed on The Space Station Freedom (SSF) solar array Flat Conductor Circuit (FCC) to determine if hypervelocity impacts could induce pyrolization of Kapton[1] and/or cross-conductor arcing. A sample piece of FCC was placed in a plasma environment and biased to +200V relative to the plasma potential. The FCC was then impacted with particles in the 100μm size range with hypervelocities of about 7km/s. These tests were unable to induce Kapton pyrolization, cross-conductor arcing, or any other plasma interaction.

Introduction

The FCC assembly is used on the Space Station Freedom solar array to carry electrical power from the strings of solar cells to the Electrical Power System (EPS). The FCC assembly is composed of multiple flat copper conductors laminated between two Kapton sheets. Nonconductive adhesive serves as the insulation barrier between conductors and adjacent conductors.

The FCC will be exposed to the Low Earth Orbit (LEO) natural and induced environments, and is therefore subject to micrometeoroid and orbital debris impacts and ionospheric plasma interactions. The following tests were performed on the FCC to determine if cross conductor arcing or Kapton pyrolization could be induced by a hypervelocity impact while being immersed in a plasma environment.

Testing was conducted in the HYPER facility at Auburn University. This facility can typically produce dozens of impacts with particles in the 10μm to 100μm mesh size range with velocities ranging from 5km/s to 12km/s. An electrothermal accelerator gun was used for the FCC tests. The FCC was wired with the small and large conductors biased to +200V and +40V with respect to the plasma potential, thus providing a cross conductor potential of 160V.

Background

Micrometeoroids and orbital debris (MM/OD) are expected to impact the FCC at hypervelocities. These impacts generate a locally high plasma density which may induce arcing between exposed conductor surfaces or the ambient ionospheric plasma. These exposed surfaces can be generated at the time of impact or may have preexisted, e.g. previous MM/OD impacts. High density gases may also exist in bubbles which form between the laminates of the FCC.

Kapton pyrolization was observed during a test at NASA LeRC.[1] During this test, a solar array panel had a small hole in its Kapton film which exposed the copper conductor surface to the plasma environment. When this panel was biased to +400V, a large current began flowing from the plasma into this hole. The resulting ohmic heating initiated pyrolization of the Kapton and the hole, which was initially 1/8" in diameter, grew to about 3/4". Since the potential was twice

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[1] Kapton® is a registered trademark of E.I. du Pont Nemours & Co., Inc.

as high as will be experienced by the SSF EPS, this phenomena is not expected to occur in Low Earth Orbit (LEO). However, it is known that arcing threshold potentials decrease when plasma density is increased, thus a MM/OD impact might possibly increase the local density enough to initiate an arc from the plasma. An objective of the test was to determine if a MM/OD hypervelocity impact could induce an arc from the plasma and initiate Kapton pyrolization.

Another concern is cross conductor arcing also initiated by MM/OD hypervelocity impacts. Cross conductor arcing of an FCC test sample was initiated during the Abraded Circuit Experiment at NASA LeRC.[2] During this test a section of FCC was biased to have 160V difference in potential between the conductors while in a vacuum environment, i.e. without a plasma. To initiate the arc, severe mechanical damage was imposed on the Kapton insulation. Although this is not expected to occur in orbit because two adjacent conductors must be exposed, a remote possibility exists that, while in a plasma environment, an MM/OD impact might be sufficient to initiate a cross conductor arc. Thus another objective of the experiment was to try to initiate cross conductor arcing with numerous simultaneous impacts and on a sample with existing damage.

Earlier hypervelocity impact testing was performed at Auburn University on a similar FCC sample. Bubbles were observed to have formed between the Kapton laminates. The bubbles were regions of high density gas and, thus, possible conduction paths for arcs. Several other impacts generated damaged areas that bridged approximately half way across the gap between two conductors. These areas were blackened by soot, also possibly becoming conduction paths for arcing. Finally, other impacts exposed the conductors to the external environment. These exposed regions could further become areas for the plasma to enter. Although highly unlikely events, a remote possibility exists which could lead to pyrolization and arc tracking.

A statement should be made about how unlikely these events could occur. Controlled manufacturing processes eliminate or minimize voids or bubbles within the FCC. Furthermore, it would require one or more exposed adjacent conductors before an arc could be generated. This would require one or more impacts to occur in a bubble. A similar scenario would be required for an arc across a gap. Finally, although MM/OD impacts which expose the conductor to the ionospheric plasma are possible, the event is highly unlikely. The exposed conductor would have to be large enough to prevent electron flow choking by the surface charge on the dielectric material surrounding the hole. In addition, the potential difference between the plasma and the conductor would have to be large enough to initiate an arc.

Test Facility

The Hypervelocity Impact Facility (HYPER) at Auburn University uses an electro-thermal accelerator technique.[3] The projectiles are accelerated by an extremely hot plasma which is generated by discharging a very large capacitor bank across an aluminum foil. The projectile load is coated onto a thin film adjacent to the foil. As the capacitor bank is energized, the current pulse which is on the order of 1 million amps, vaporizes the aluminum foil. The resultant gas explodes and accelerated the projectile load down the launch tube. During acceleration the projectiles can be shattered or ablated into numerous smaller particles. As a result only the maximum size of the particles can be predicted. Furthermore these particles obtain a wide distribution of velocities which is related to the mass of the projectile load. Although the particle sizes and velocities can not be known *a priori*, they can be determined to some extent during the test. Instrumentation and cameras have been installed which allow for the measurement of the X & Y coordinates of each impact, the number of impacting particles, the velocity of some particles, the duration of the optical flash after impact, and the approximate cone angle of the ejecta. In addition, a very thin Mylar[2] film can be placed up range of the target to record the diameter of the impacting projectiles. Since the ballistic limit of the Mylar is greatly exceeded, the projectile can pass unaffected through the film, leaving a neat hole.

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[2] Mylar® is a registered trademark of E.I. du Pont Nemours & Co., Inc.

Experience with HYPER has shown that maximum projectile sizes are currently limited to 100 micron or less. Larger particles were shattered during acceleration. Furthermore, microscopic examination revealed that the particles were not spherical but were oblong. Thus the mass of a particular particle could vary from 0.5 to 3.0 times the mass of a spherical particle. It has also been determined that velocities are limited to less than 10 km/s. Faster particles are shattered as they pass through the Mylar film.

During the tests, current and voltage changes were monitored on leads connected to the FCC. Electro Mechanical Interference (EMI) was also observed by the instrumentation due to the large current pulses generated during the firing of the HYPER gun. This disturbance, however, did not interfere with the test results. The distance between the breech and the target were sufficiently great enough to allow the EMI to subside before the projectiles impacted the FCC sample.

The firing discharge also emits large amounts of light and Ultraviolet Radiation (UVR) which have been shown to generate photo enhanced electrical conduction on some surfaces. To avoid this, a photo mask was placed ahead of the target. The mask prevented light exposure on the target while allowing the projectile to pass through unabraded.

Test Procedure

The test facility set up is shown in the Figure 1. The wiring arrangement provides for the following under non arcing conditions:

Conductor	Potential w.r.t. Plasma	Current
Small	+200V	0.5A
Large	+ 40V	1.0A

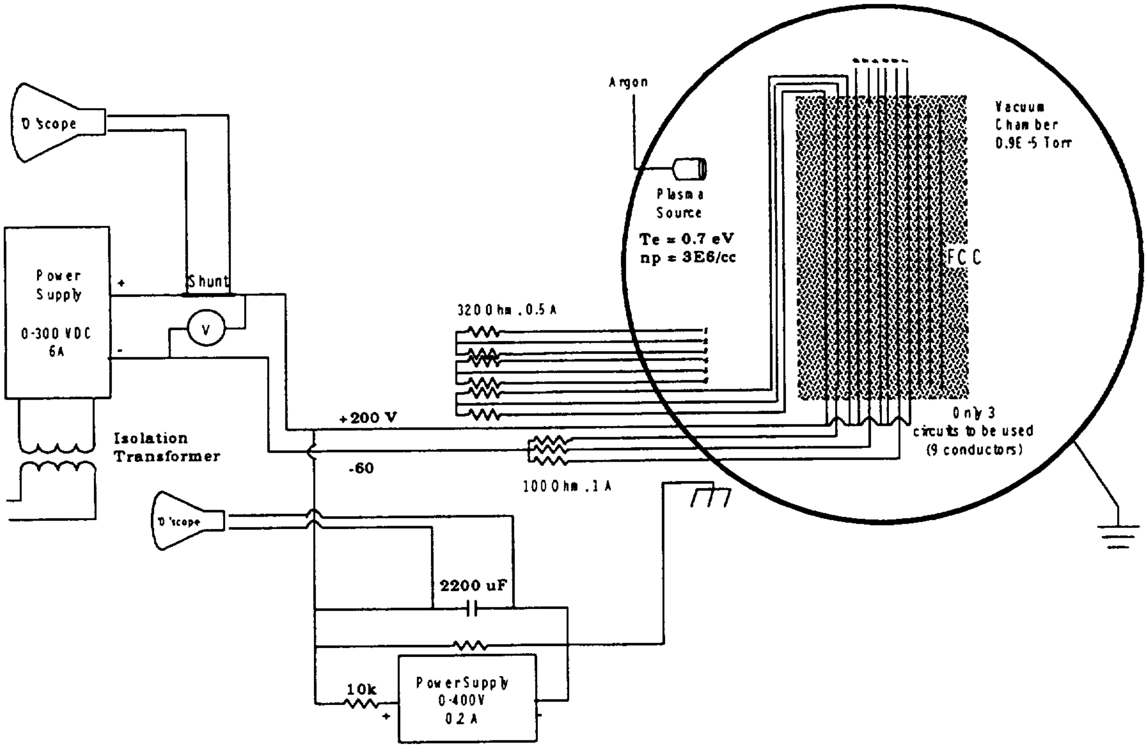

Figure 1, Test Schematic

If an arc occurs between two conductors, the small power supply is to maintain the potential at +200V and the large power supply will provide up to 2.6A of current through the arc. If an arc occurs between the plasma and the small conductor, the large capacitor will discharge through the plasma. If both arcs occur simultaneously, both of the above will occur but the +200V potential will not be maintained.

The 320W and 100W resistors provide a voltage divider network which creates a 160V potential difference between the small and large conductors. The divider also provides current limiting for the large power supply. The 10kW resistor on the small power supply is for current limiting of the small power supply so it is not over loaded during arcing. The 20kW resistor across the small power supply is merely a load resistor for power stability. This resistor also serves a safety purpose as a discharge path for the system.

The 2200µF capacitor serves as an electron source for the plasma. The small power supply and the plasma in the chamber are relatively small and, thus, do not provide a sufficient source for a plasma arc. There is no capacitor on the large power supply because it alone can continuously supply the required current for a cross conductor arc.

The plasma environment was provided by a hollow cathode plasma source using Argon gas. The plasma characteristics were not measured at the time of the test but are estimated to be as follows:

Electron Temperature	$T_e = 0.7$ eV
Plasma Density	$n_p = 3E6/cm^3$

Two sample sections of FCC were tested. The first section was one previously shot by earlier hypervelocity impact testing and contained existing damage. The section was initially tested under static conditions. Such existing damage would determine whether arcing could occur at previously damaged sites. Two tests were conducted. The tests investigated whether arcing could occur at and between new and existing sites. The second section was only subjected to a vacuum in order to observe the possible formation of any bubbles, their size and location.

Test Results

The first section of FCC was placed in the test chamber and the chamber evacuated. The plasma source was then activated and equilibrium obtained. The power supplies were turned on and adjusted to provide the proper current and voltage levels. No plasma interactions were observed.

The HYPER gun was then fired. Although the instrumentation observed the EMI generating from the gun, no other interactions occurred. A plot of the large power supply current output is shown in Figure 2. The HYPER gun was reloaded and a second shot of projectile load was fired at the FCC sample. Again, no plasma interactions were observed. The sample was removed from the test chamber and examined. Although hypervelocity impact craters were evident, there were no signs of Kapton pyrolization or arcing.

During the above test, the second sample of FCC was placed in the bottom of the test chamber. Upon removal there was no evidence of large bubbles forming between the laminates.

Discussion

These tests were unable to generate any pyrolization, cross conductor arcing, or other events at a bias potential of +200V. This is what was expected. It appears that the plasma interactions generated by the hypervelocity impacts are not sufficient to trigger these events.

Conclusions

These tests results along with those reported in previous investigations,[2] indicate that hypervelocity impact induced pyrolization and cross conductor arcing are unlikely to occur on the Space Station Freedom Flexible Collector Circuit.

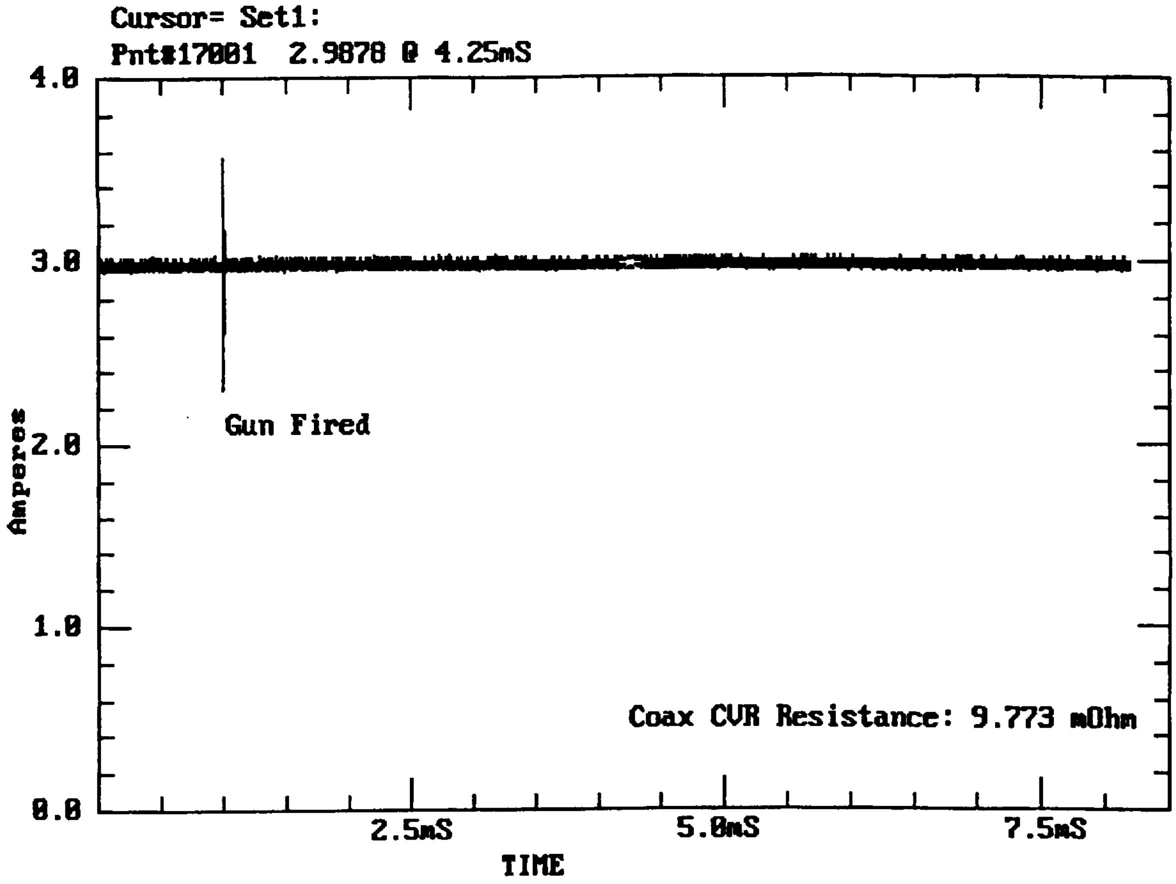

Figure 2, FCC Current vs. Time

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