N80-10...

Contents

5. Charge Distributions Near Metal-Dielectric Interfaces Before and After Dielectric Surface Flashover

James W. Robinson
Electrical Engineering Department
Pennsylvania State University
University Park, Pa.

Abstract

Flashovers on dielectric surfaces of spacecraft will produce currents to adjacent metallic surfaces and in many cases may be initiated by phenomena at the interface between metal and dielectric. A technique has been developed for measuring surface charge distribution near interfaces without placing any measuring apparatus near the face of the samples. This paper reports the results of measurements which have been made on FEP Teflon and Kapton dielectrics, before and after flashover, with various types of interfaces. Also given are data showing mean time between flashovers for various configurations exposed to a variety of environmental conditions. Several charge transfer mechanisms are considered as means by which stable charge distributions may be maintained near interfaces.

1. INTRODUCTION

Many of the flashovers which occur because of differential charging of a spacecraft surface will be initiated by phenomena near a metal-dielectric interface. This is especially true if the conductive frame of the spacecraft is maintained near local space potential by an active emitter while the dielectric becomes highly charged because of substorms. This report deals with phenomena at the interface

PRECEDING PAGE BLANK NOT FILMED

so as to ascertain the conditions for flashover and to seek means of preventing flashover. Charge distribution measurements are the principal diagnostic tool.

The flashover is a process whereby negative charges adhering to a dielectric surface are abruptly released and transported tangentially to a nearby grounded conductor. Punchthrough is not considered. The charge distributions on the dielectric are formed by an impinging electron beam that is monoenergetic though unfocused. The breakdown process is suggestive of the failure of vacuum bushings except that the bushings fail because of cathode phenomena[1] whereas the system of interest has a remotely located cathode which plays no part in the flashover phenomena.

This report presents charge distribution data and flashover probabilities for different types of interface. From charge distributions, one can calculate electric fields and estimate limits where flashover becomes probable. An analysis of various charge transport mechanisms below the flashover threshold will lead to an eventual understanding of the phenomena controlling flashover.

2. EXPERIMENTAL PROCEDURES

2.1 Preparation of Specimens

Results described here are for 0.13 mm (5 mil) sheets of FEP Teflon having a silver-inconel coating. The coating is grounded with the specimen facing the electron beam such that charges on the surface of the sheet will induce comparable charges on the underlying metal film. When the metal film is segmented and each segment is grounded, then the surface charge distribution can be inferred by measuring the charges induced on each of the underlying segments. The schematic shown in Figure 1 illustrates the technique where it should be noted that the electrometer configured for charge measurement maintains the associated segment at virtual ground.

The charge data must be coupled with either segment areas or segment capacitances. Areas were determined by scaling from enlarged photographs and capacitances were measured directly by applying voltages of 500 and 1000 V to drops of aqueous salt solutions standing on the upper surface of the specimen. The two measurements were compatible with handbook data of 2.1 for a dielectric constant, though the capacitance measurements were the more precise and were used almost exclusively. A typical capacitance per segment was 1 pF.

The interface for many of the measurements was formed by placing a grounded metal aperture over the specimen. Variations of diameter, aperture thickness, and material were tried. In other measurements, the same type of aperture was used but a slit was cut through the dielectric sheet so as to expose the underlying

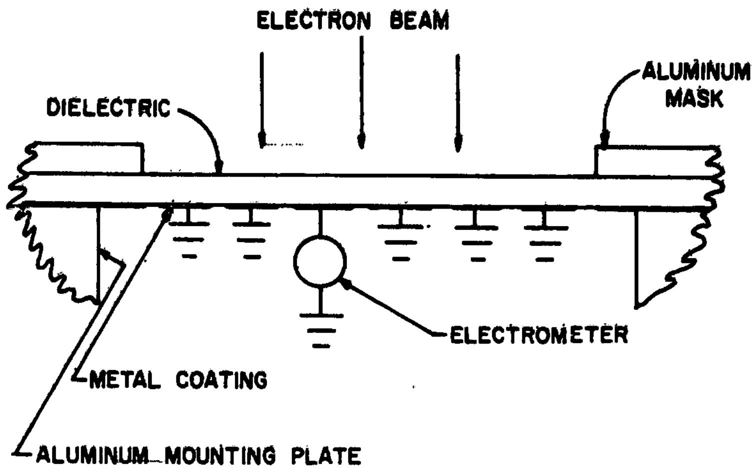


Figure 1. Mounting of the Dielectric Specimen (Film Thickness Exaggerated)

ground plane. In these latter cases, the ground plane was reinforced with a layer of conductive epoxy backed with stainless steel shimstock.

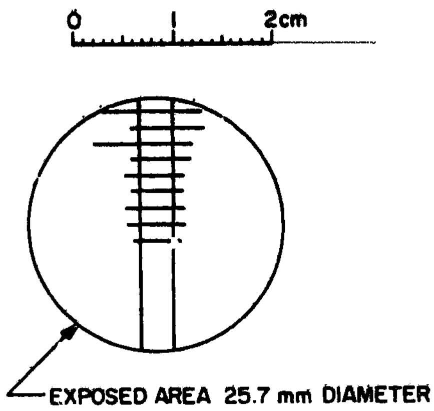
The segments were cut in the ground plane by means of an electrical discharge machining technique. A repetitive discharge from a 100 pF capacitor at 1 kV was used. With the use of guides the etching point could be moved so as to cut lines of about 0.2 mm in width though in practice wider lines were used. When the lines were too fine, flashovers would induce breakdown between the segments. The smallest segments used were approximately 1.5 mm wide and 4 mm long, this being the smallest size for which epoxy bonding of leads was convenient.

A line drawing from a photograph of an actual specimen is shown in Figure 2. The view is from the direction of the electron beam. The circular aperture exposes the transparent dielectric sheet and the underlying reflective ground plane. The etched lines are visible through the film and are easily photographed by the use of backlighting. The first segment in the illustration is partially hidden by the aperture.

2.2 Test Chamber

The specimen was inserted into a stainless steel vacuum chamber as illustrated in Figure 3. The various aspects of the system are described below.

The electron source was of simple construction having a heated tungsten filament and its aluminum enclosure maintained at a fixed negative voltage. Electrons from the recessed filament would emerge from the hole in the box and be accelerated toward the grounded supporting frame. They would pass through a



SEGMENT	CAPACITANCE (pf)	DISTANCE d (mm)
1	.56	.5
2	.87	2.1
3	.72	3.8
4	.86	5.4
5	.88	7.1
6	.84	8.9
7	.86	10.4
8	.88	12.0
9	.80	13.8

Figure 2. Typical Specimen Configuration

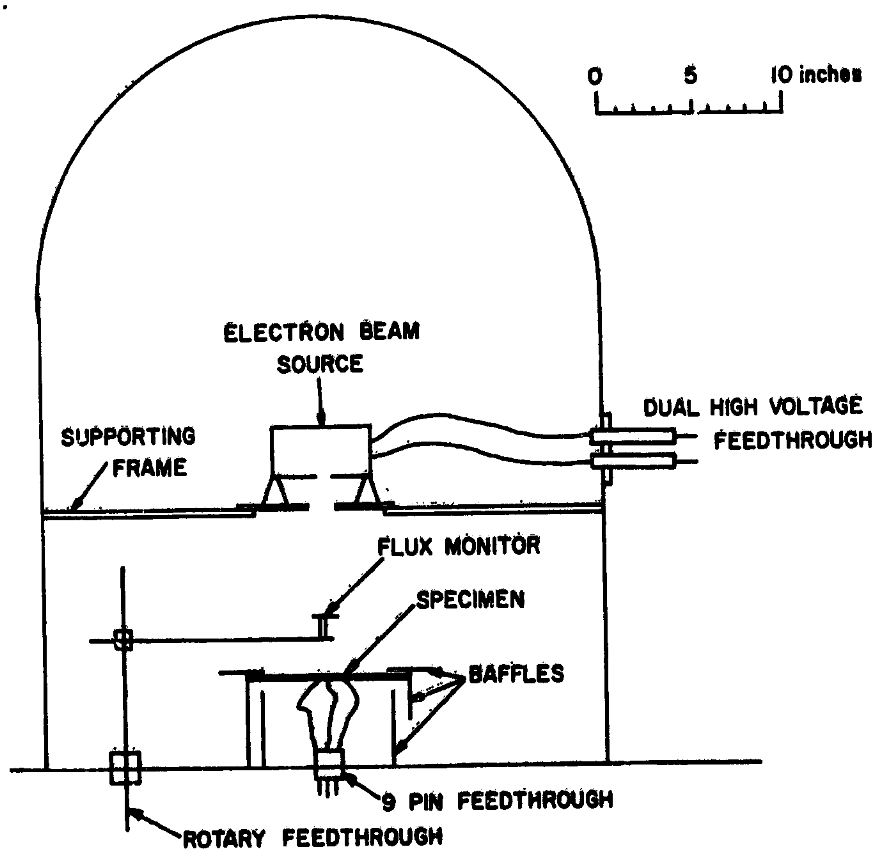


Figure 3. Placement of Apparatus in Vacuum Chamber

second hole in the frame and drift at constant velocity toward the specimen. The diameter of the beam at half-maximum intensity on the target was approximately 8 cm as determined by sensors on the specimen plane. Thus, specimen diameters were kept to less than 5 cm for all experiments. The beam source was fed by high-voltage feedthroughs remotely located from the other feedthroughs where sensitive measurements were being made.

The beam intensity was monitored by a small probe which could be swung into position above the specimen. Current to the probe was measured by an electrometer which held the probe near the ground potential. A geometrical factor was computed for converting the probe current to effective current density at the specimen face. Though the accuracy of this determination is not high, it is still adequate for comparing fluxes and providing reproducibility.

The specimen was mounted on a platform surrounded by baffles which were to keep scattered electrons from the sensitive leads. These leads were kept short and connected by a multipin, high-voltage feedthrough to an external terminal box where various electrical connections could be made.

The chamber was evacuated to a base pressure of 10^{-6} torr with a turbomolecular pump. Pressure was monitored. A controlled leak was available but used little because varying the pressure had little effect upon the data.

2.3 Data Collection

Procedures were developed to reduce the impact of spurious events and systematic errors. In addition to the occurrence of occasional inconsistent data points, all data reflected the effects of electrometer drift and residual surface charges.

Drifting of the electrometers occurs because of charge leakage through the dielectric sheet but this was negligible and not measurable with FEP Teflon. Some tests with Kapton showed leakage but otherwise behavior similar to FEP Teflon. Of much greater significance was the scattering of electrons through the baffles to the back side of the specimen. This effect was controllable to a point where short term drifts of say a minute were negligible. Long term drifts were of little consequence and could have been due either to leakage or to scattering. Another source of drift was that due to humid air in the terminal box. This problem was controlled with dessicant.

The measurement of charge requires the ability to remove all charge from the specimen before and after a charging cycle. One simple way of removing charge, but a slow way, was to raise the pressure to 10^{-3} torr and to wait for approximately 1 min. A quicker and equally effective way was to use secondary emission from the surface. With proper adjustment of the electron beam energy, the secondary emission coefficient would exceed unity and the surface would lose charge. With the proper sequence of beam voltage adjustments, the surface charge could then be brought to an adequately low value.

Two electrometers were used to monitor two segments simultaneously. Several sets of measurements then provided a basis for combining data from different runs with an assurance of consistency from one run to another.

Flashovers were easily observed by recording electrometer outputs on a strip chart recorder. The abrupt loss of charge on a segment was observable as a discontinuity on the trace. Partial and complete discharges have been observed through the great majority have been complete.

3. STEADY STATE MEASUREMENTS

3.1 Charge Distributions

Detailed charge measurements were made for the FEP Teflon specimen illustrated in Figure 2. The diameter was 2.5 cm as determined by an aluminum aperture plate having a thickness of 1.3 mm. Measured segment capacitances were used to convert measured charges to surface potentials which are shown in Figure 4. Away from the boundaries, the potential is approximately the beam potential less the energy at which the secondary emission coefficient is unity. Incoming particles thus strike the surface so as to release an equal number of secondaries. The data of Willis and Skinner[2] indicate a unity crossover for PTFE Teflon of 1.8 kV which corresponds well with Figure 4. Near the boundaries, the potential is depressed such that a gradient of approximately 10 kV/mm is established. If one applies the data of Willis and Skinner to the depressed region, he concludes that the secondary emission coefficient in that region is less than unity such that some auxiliary charge release mechanism is acting in that region to maintain a steady state.

Charge measurements have been made for another specimen similar to that of Figure 2 except that it has a slit of 1 cm length through its center. Steady state conditions could not be achieved at such high voltages as for the first specimen, but charges were measured and potentials calculated as shown in Figure 5. Also shown in the figure is a curve at 10 kV taken from Figure 4 and positioned for comparison of the gradients with and without a slit.

It is evident that with the slit a high gradient will exist across the cut surface of the dielectric, this being as high possibly as 7 kV/0.13 mm or about 50 kV/mm.

Numerous other mappings have been made with results being essentially similar to those already shown. The edge effects are similar for a 5 cm diameter specimen, for a specimen with a copper aperture, and for a Kapton specimen.

Highly significant is the fact that steady state distributions do not depend upon electron flux density. From a steady state with a given flux, the electron source filament can be cooled until the flux is zero and no change in the charge is observed.

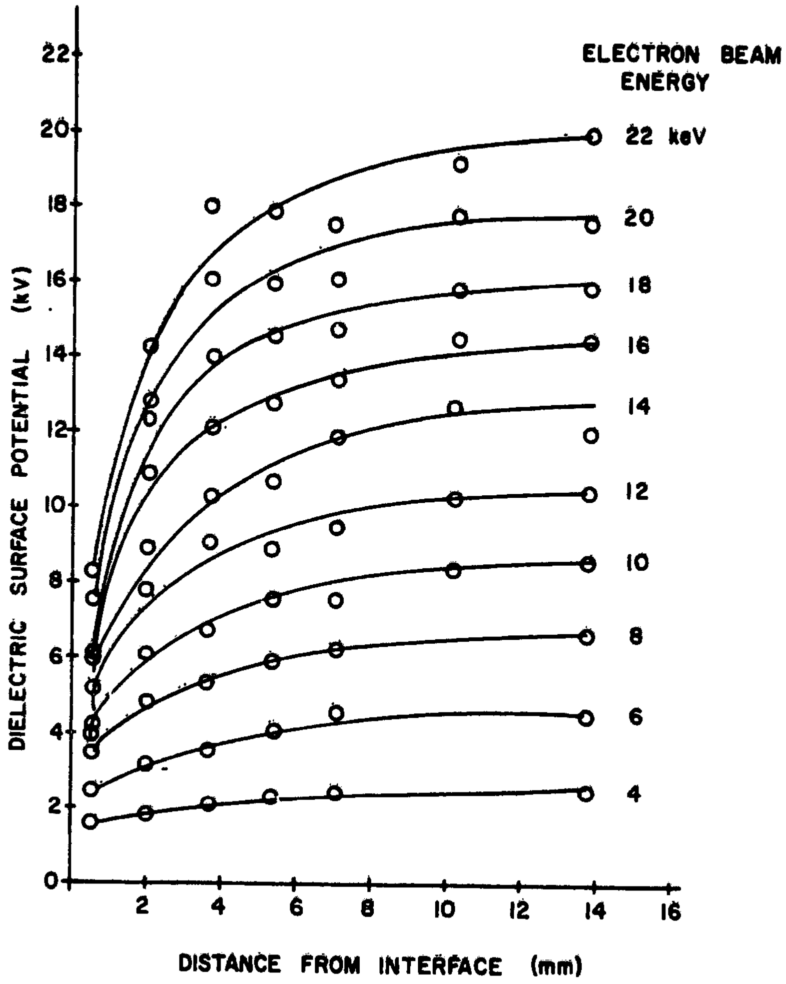


Figure 4. Steady State Surface Potentials for FEP Teflon

However, at very high fluxes exceeding 1 $\mu A/cm^2$ a drop of perhaps 5 percent of the surface charge is observed.

3.2 Equipotential Contours

Once charge distributions are known, Laplace's equation can be solved. The method used here was approximate, being most accurate near the surface and the interface. It involved approximating the problem with a two-dimensional model, doing a conformal transformation, and solving by use of separation of variables. The data points for the 20 kV case of Figure 4 were the basis of a calculation shown

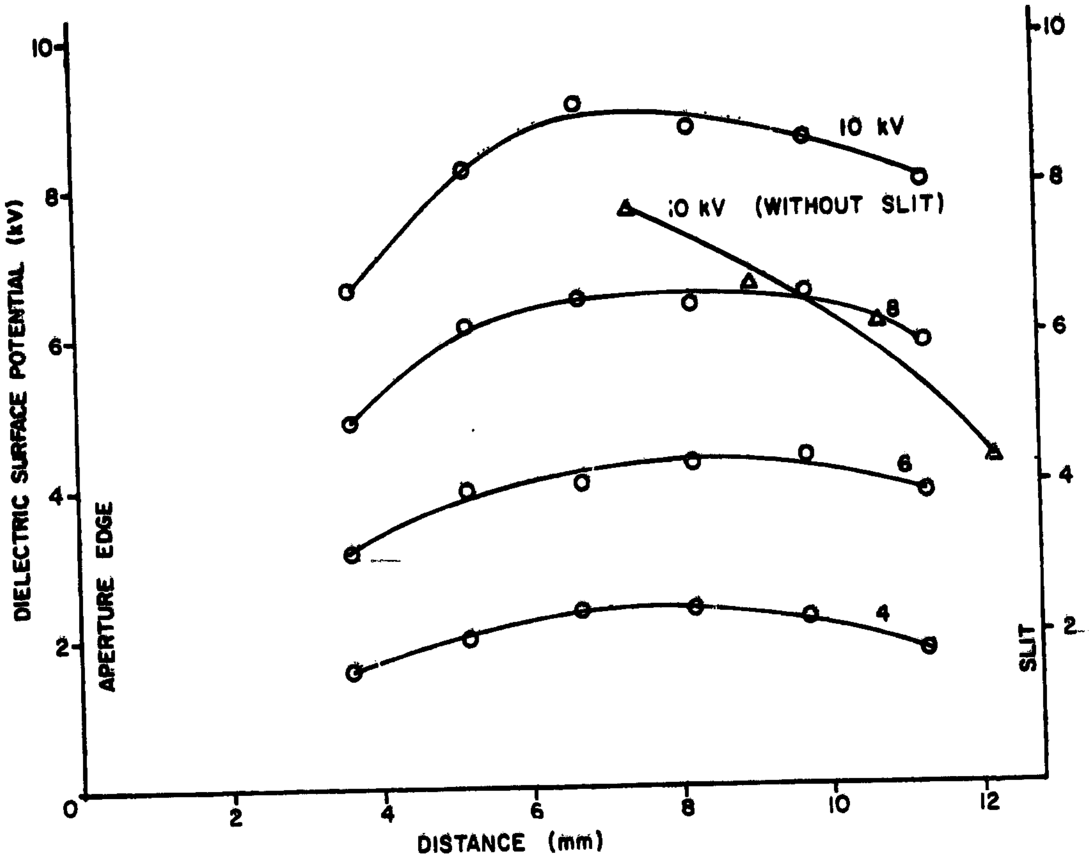


Figure 5. Steady State Potentials for Specimen With Slit

in Figure 6. The crucial point to be noted here is that the electric field has a normal component toward the surface.

3.3 Charge Release Mechanisms

The gradients near an interface are established through a balance of various charge transfer mechanisms. The fact that the balance is independent of primary flux density is an indication that all processes involved are proportional to primary flux. Various possibilities include field-enhanced secondary emission, x-ray production from the beam striking the aperture plate, ion neutralization, and bombardment-induced conductivity of the dielectric. The first of the suggestions is considered to be the most appropriate.

Measurements with a copper aperture were made to test for the possibility of x-ray effects. Copper was deliberately chosen because of its K-edge at 9 kV. If

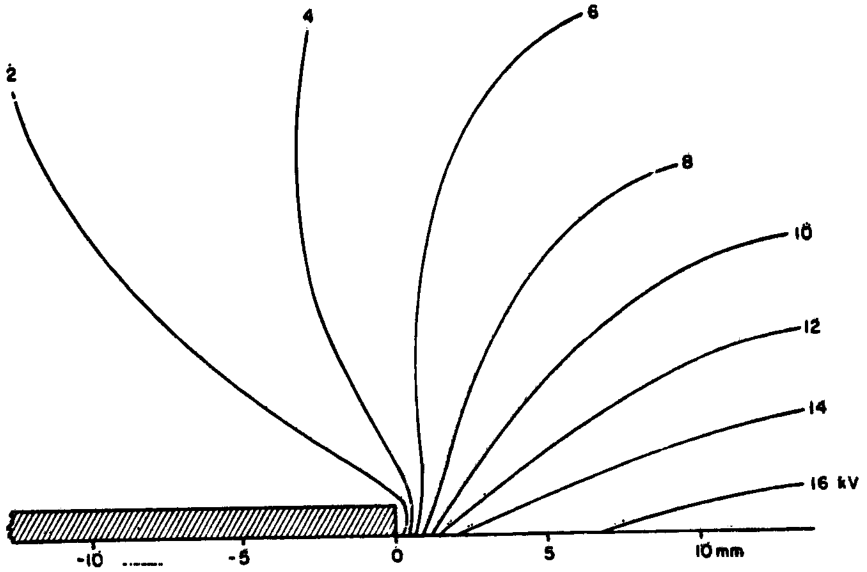


Figure 6. Equipotential Lines for Exposure to a 21 kV Beam

the charge distributions showed anomalies with 9-kV beam voltages, then x-rays would likely have a significant rôle in the charge balance. However, no differences could be found between measurements with copper and aluminum.

Ions might be attracted to the negative dielectric surface, yet they would go preferentially to the most negative center region and not to the edges where their contribution would be needed.

Though little information is at hand regarding conductivity of the dielectric under bombardment, it is felt that this phenomenum is not of sufficient magnitude, nor sufficiently linear, to account for the observed charge distributions.

Available data indicate that the secondary emission in the depressed regions near interfaces is inadequate to compensate for the incoming primary flux. Also, secondaries are accelerated away from the surface by the normal component of the field such that they cannot interact with the surface to cause an additional release of electrons. Note, however, that the data of Willis and Skinner[2] was recorded with techniques which minimized the buildup of charge on the dielectric surface and thus the field. It is possible that the secondary emission coefficient is increased in the presence of the field such that a steady state is maintained in the depressed regions.

4. FLASHOVER MEASUREMENTS

4.1 Specimen Without Slit

The probability of flashover has been found to be very low for Teflon specimens covered with the 1.3 mm aluminum aperture plate. Generally for all specimens without slits, but with aperture plates, the flashover rates have been low.

The flashover rate for the specimen of Figure 2 has been measured at various flux densities for a beam voltage of 21 kV. The rate is not constant but decreases with time, probably because of cleanup of the dielectric surface. The measurements shown in Figure 7 were made with a relatively dirty specimen which had not been long in vacuum. Even then a run of 1 hr at 0.16 $\mu A/cm^2$ showed no flashovers. The flashovers which occurred showed a complete loss of charge from the surface of the specimen. After long exposure the surface of the specimen near the interface became frosted. For these tests the current levels were such that a steady state charge distribution was established in a few seconds. The system would reside in that condition for hundreds of seconds, exposed to an electron flux, before a flashover would occur.

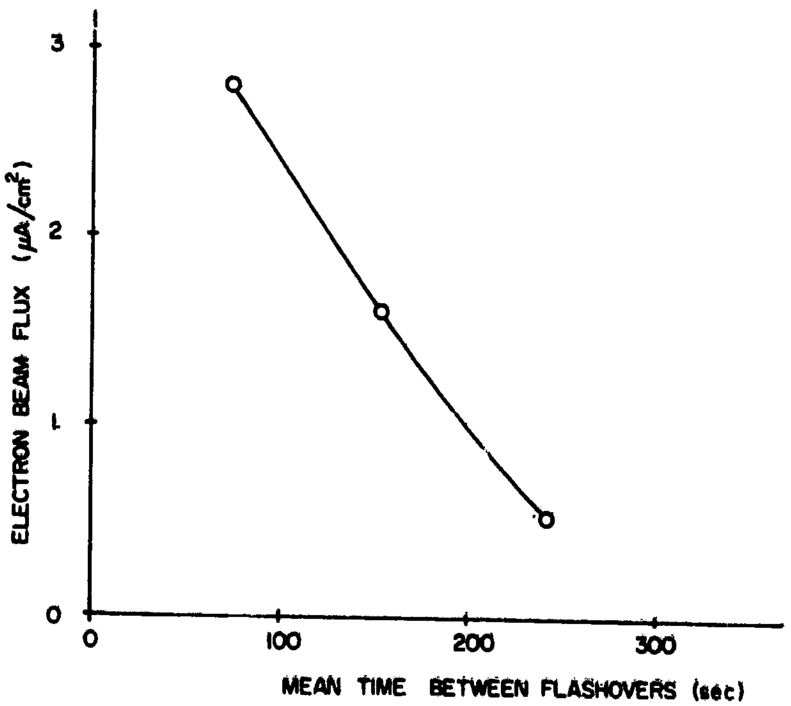


Figure 7. Flashovers in a 21 kV Beam

4.2 Specimen With Slit

When a slit is cut in a specimen, the flashover rate increases drastically. Steady state is not attainable much above 10 kV. As before the flashovers cause a complete loss of surface charge. Visual observation shows light bursts concentrated on the slit when flashovers occur. Data points are shown in Figure 8 where the influence of both beam voltage and current density are shown.

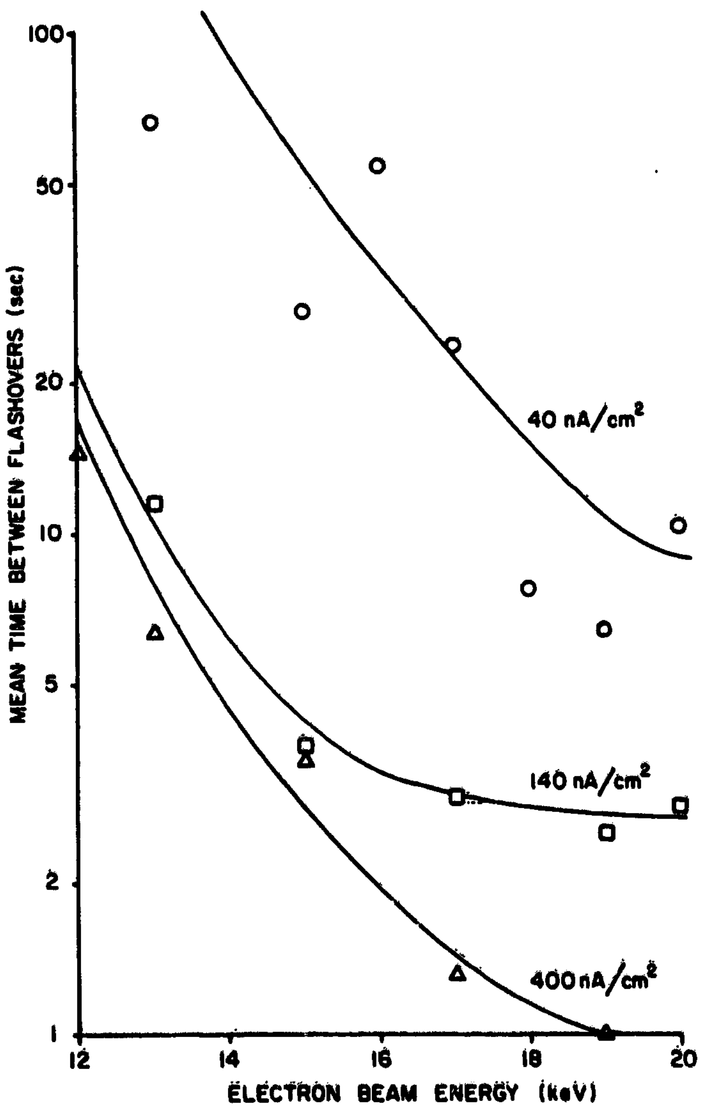


Figure 8. Flashovers for a Specimen with Slit

4.3 Partial Flashovers

Partial flashovers have been noted, these being such as to leave some charge on the surface of the dielectric. Most of these observations were for FEP Teflon with a stainless steel aperture have a thickness of 0.08 mm. Furthermore, these partial flashovers occurred during the charging transient as shown in Figure 9. Two sequences are shown with the charges induced on two segments plotted against time. For this specimen, segment 5 was in the center, 3 near the edge, and 9 intermediately placed. The final steady state charges at 21 kV are consistent with expectations from Figure 4. No pattern of partial flashovers was distinguished except that in most cases only a single flashover occurred during the charging transient.

On rare occasions a single segment will lose a small fraction of its charge after having been in steady state for some time. Such events have not been counted in determining the mean time between flashovers shown in Figures 7 and 8.

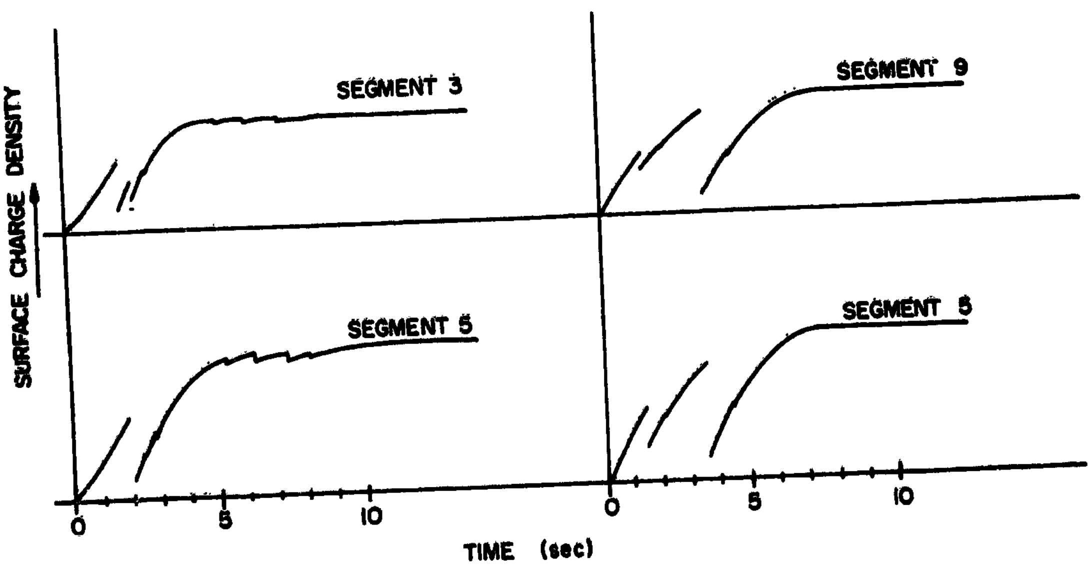


Figure 9. Partial Flashovers During Charging Transients

5. CONCLUSIONS

Measurements have demonstrated that gradients of 10 kV/mm can exist on the surface of dielectric materials with the probability of flashover being practically insignificant. The gradient is maintained by a balance among charge transfer processes which are thought to be dominated by secondary emission, although appropriate data to show this are unavailable.

The design of the metal dielectric interface has a marked effect upon the probability of flashover. An interface which exposes an edge of a dielectric sheet creates a strong field which initiates flashover at a relatively low level of charge on the dielectric surface. The threshold level for the onset of flashovers can be approximately doubled by covering the edge of the sheet with a ground plane.

The configurations investigated are not particularly useful for applications and, as a result, extensions of the work to multiple-aperture systems are anticipated. Breakdown probability and the propagation of flashover from one region to another are topics of interest. Also, the effects of punchthrough are to be investigated.

Acknowledgments

S. G. Ehrenberg and N. Q. Nguyen have made significant contributions to the work described here. The support of the National Aeronautics and Space Administration under Grant NSG-3097 has been appreciated.

References

1. Sudarshan, T.S., and Cross, J.D. (1973) DC Electric-field Modification Produced by Solid Insulators Bridging a Uniform-Field Vacuum Gap, IEEE Transactions on Electrical Insulation, EI-8 (No. 4):122-128.
2. Willis, R.F., and Skinner, D.K. (1973) Secondary electron emission behavior of polymers, Solid State Communications 13:685-688.