Contents

8. Surge Current and Electron Swarm Tunnel Tesfs of Thermal Blanket and Ground Strap Materials

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1. INTRODUCTION

This technical memorandum will describe the results of a series of current conduction test8 with a thermal-control blanket to which grounding straps have been attached. The material and the ground strap attachment psocedure will be described more fully in Section 2. The current conductioh tests consisted of a surge current examination of the ground strap and a dilute flow, energetic electron deposition and transport through the bulk of the insulating film of this thermal blanket material. Both bf these test procedures have been used previously with thermal cbntrol blanket materials. The surge curredt test procedure (arid accompanying teet results) has been previously described in Hoffmaster et al.[1] The electron deposition procedure (and accompanytng results) has been described in Hoffmaster and Sellen.[2] Because of the length of these previous memoranda, there will be no ettempt to represent here the conteht of these papers, and it is recommended that these earlier teet procedures and results be read as a portion of the total TRW in-house examination of thermal control blahket material response to particle injection and to surge currents.

Without presenting specific experimental détails here, it wtll be noted that the behavior of the material to these test procedures is considered as a distinct

improvement **over** previously observed behavior. Since the ultimate selection of spacecraft surface materials w 111, undoubtedly, involve many different features of the materials, superior performance to surge currents and deposited currents may **not** be the ftnal, and crucial, material aspects. In view, however, of acknowledged problems in **charge** up discharge in magnetic substorms at geosynchronous altitudes, the material performance tb **be described here** under certain simulations of these space environmental conditions should be considered as a strong reason for their use.

2. MATERIAL DESCRIPTION

The thermal control bla ket material used here (ORCON **KN-**10) is a 0.0005 in. **(1.27 X 10⁻³ cm)** Kapton* film **with a** rear face of Vacuum Deposited Aluminum (VDA) to **a** depth of $\sim$**1000 Å** . At the rear (exterior) face of thb VDA film, a grid of NOMEX ribbon thread (described ad a Mylar-like insulator) is attached. The grid is $\sim$6 threads **per** inch in **each** bf two directions. The thread dimensions are $\sim$**0.0025 in.** X 0.020 in.

The ground straps are aluminum foil of **0.75** in. width and 0.002 in. thickness, bonded **tu** the VDA layer with a cbnducting epoxy. The joints are overlaid with a **1.00 in. X 1.25** in. aluminum tape **as** per the current DSCS fabrication technique. Each kapton sample had an area of 3 in. X **4** in. **and was** equipped with twb grounding straps.

3. GROUND STRAP SURGE CURRENT TESTS

3.1 General Considerations

In **the** surge current tests, the current is injected over **a** broad area at the midplane of the VDA film **on** the rear face of the Kapton and **is** conducted Into a single ground strap. In principle, then, **the** current **flow is** in the VDA film and hence to the conducting epbxy and to the ground strap. In practice, it **is** apparent that, in addttion **to** the conducting path **above,** current flow may also (if necessary) take place in the NOMEX grid.

The **surge** current generator **is** a power supply which charges a capacitor **to 10,000** vblte **and** a hydrogen thyratran ahd series current limiting reststor. The firing of the hydrogen thyratron causes the capacitor to discharge through the

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*Some of the tests performed with **the** 0.0005 in. material were repeated with ORCON utilizing a 0.003 in. Kaptdn base ftlm. See Section **4.3.2** for these teste.

series resistor ($100\,\Omega$) and the **VDA** film/conducting epoxy/aluminum ground strap
The total charge flow is determined by the capacitance and the charging voltage
For the capacitors uacd of 3.6×10^{-9}, 10.0×10^{-9} and 100×10^{-9} E and the charging voltage of 10,000 volts, it follows that tatal charge flows for the various tests
were ~ 36, **100,** and $1000\,\mu c$. The characteristic durations of these current surge e
were ~ 0.36, 1.0, and $10.0\,\mu sec$.

Two types of resistance measurements were made. The first of these is a
steady-state measurement fram the input clamp to the output clamp on the surge
current generator, made after **each** current-buret. Only very low sensing voltages
are used in these measurements. The second resistance measurement is a
"dynamic" measurement, and is made during the time of the **high** current passage
through the **VDA**/ground strap combination. Significant differences **may** exist
between these two measurements, particularly at the high burst number level.
where the removal of **VDA** near the ground strap bond has taken place.

3.2 Steady State Resistance

Ohmmeter type measurements were carried out on six ground straps. The
results of these resistance measurements are given in Figures 1 through 6 as a
function of the number of current bursts applied and for the three levels of capaci-
tance in the high voltage storage capacitor.

Figures 1 and 2 illustrate results for a 3600 pF capacitor, charged to IO,000
volts and with a series resistance of $100\,\Omega$ (leading to a peak surge current of
100 A). The shape of the R (n bursts) curve is similar to those obtained previously.
For a large number of bursts, the steady state, post-burst, resistance remains
approximately constant. Above some burst number, however, increases in resist-
ance are comparatively rapid. In previous tests of ground straps, these rapid
increases in resistance were attributed to the removal of the last remaining
portibns of the **VDA** film leading into the conducting epoxy bond.

While removal of **VDA** occurs for the present samples **(as** well as for previous
ones), there are two major differences between the behavior observed here for the
added **NOMEX** grid and the previous samples where the grid has been absent. The
first major difference is that the number of bursts required to reach the "knee" of
**the R (n) curve is now considerably larger than for the previous ground straps.
For example, (see Figure 7, Hoffmaster et al[1]), the knee of R (n) curve for
3.6×10^{-9} F, $100\,\Omega$, and 10^4 volts was observed at ~ 300 bursts for the ground
straps used there, while in the present case, over 1000 bursts were required to
reach the rapid rising portions of R versus n.**

**A second major difference between present and previous results is that, for
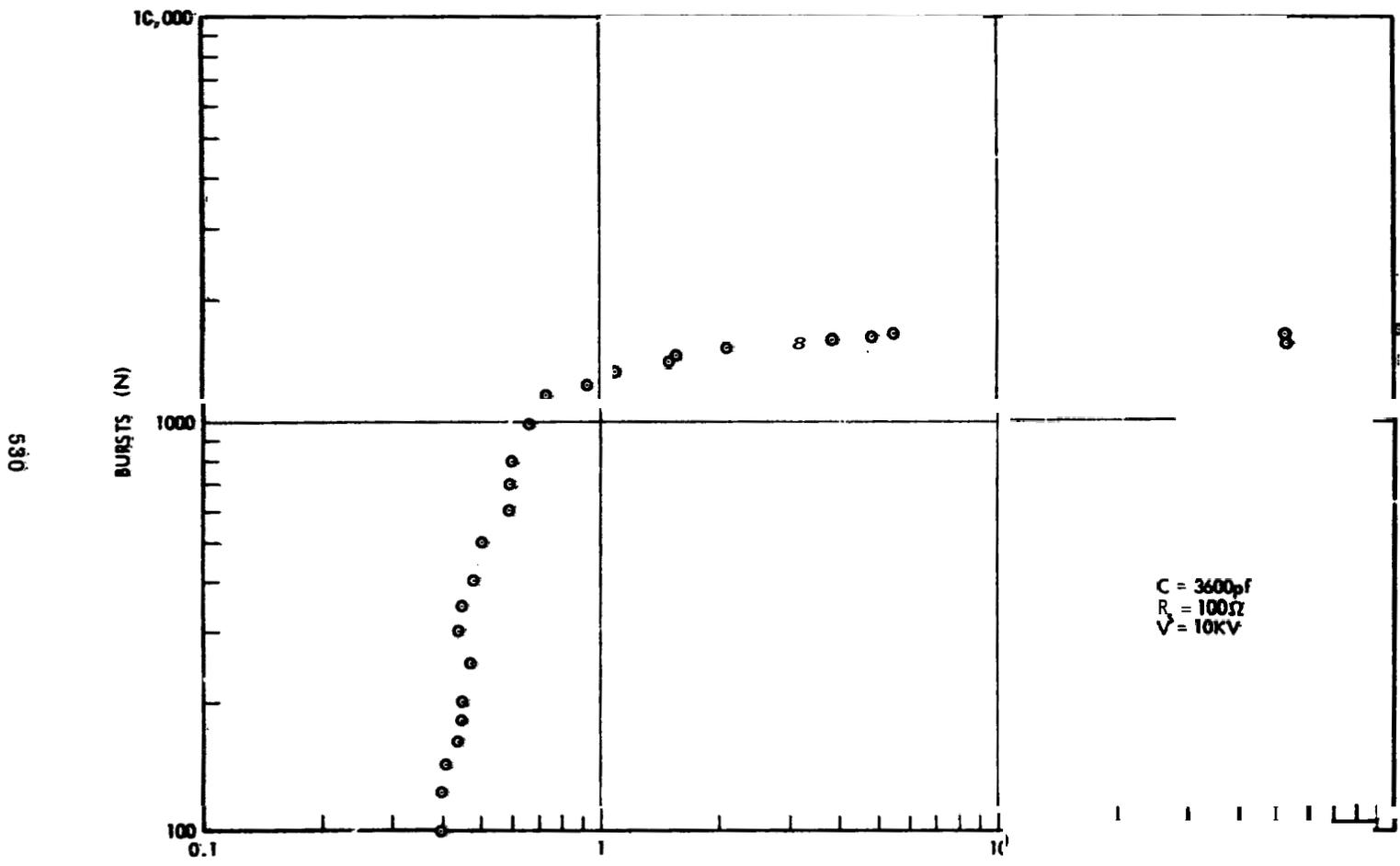the present (NOMEX aided) ground strap, visible surface arcs did not occur, even**

Figure 1. Resistance of VDA/NOMEX/Groundstrap Sample 1 as a Function of the Number of Current Burets. Initial surge current = 100 A and tatal charge throughput = 36 μc
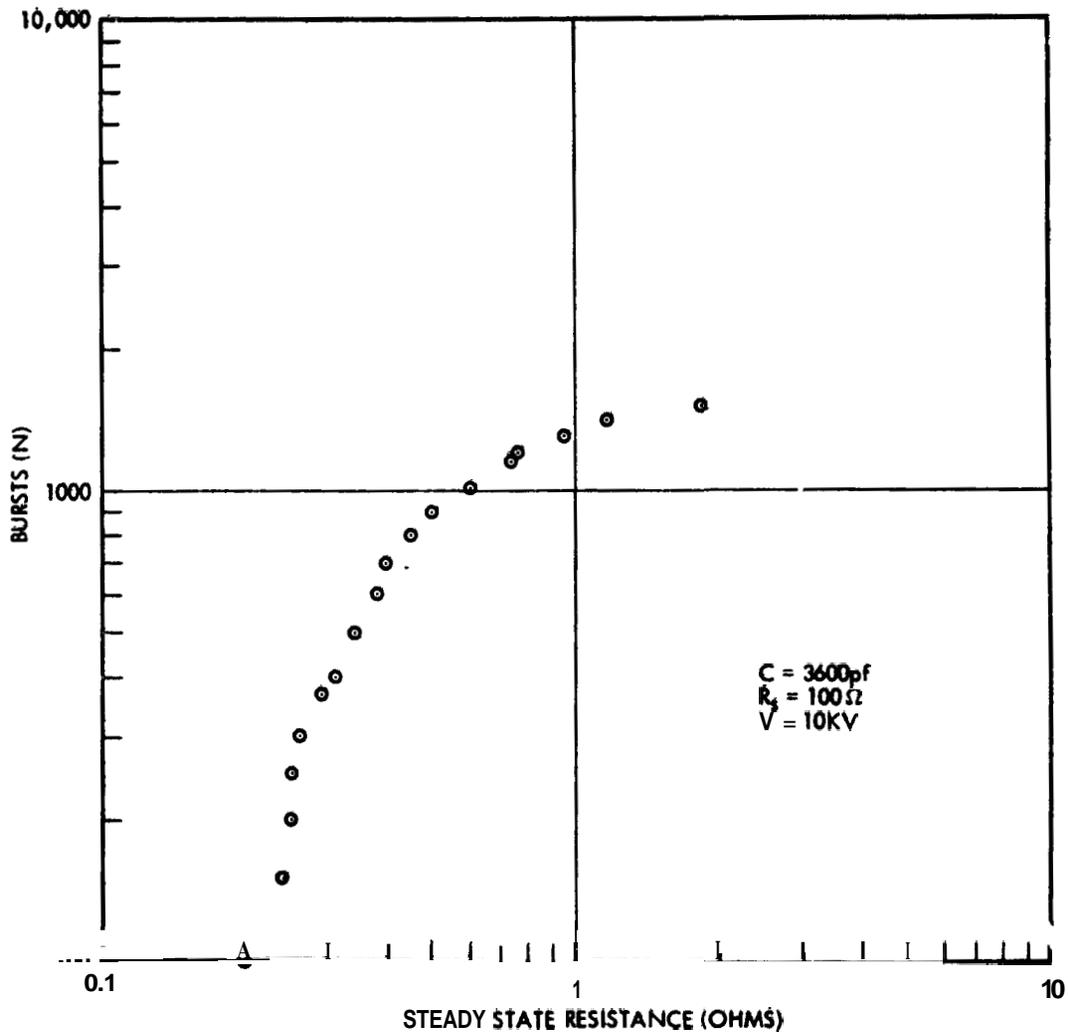
Figure 2. Resistance of VDA/NOMEX/Groundstrap Sample 2 ai a Function of the Number of Current Bursts. Initial surge current = 100 A and total charge throughput = 36 μc.

after the VDA film had teen removed from the region of the bond. It is apparent that the presence of the NOMEX grid provides alternative conduction path$ end that the conduction of this dew condtructton does nbt result in the metal-to-metal arcs across dielectric surfaces observed earlier. This is e significant improvement in performance and indicates a large reduction in surface discharge current noise, should conduction be required and if the; VDA film near the bond has been removed by previous current bursts. Section 3.3 will consider these dynamic current conductidn processes further.

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Figures 3 and 4 illustrate the steady state resistance as a function of the num-
ber of bursts for a larger capacitor than above. The increase in C from 3.6×10^{-9}
to 10×10^{-9} F reeults in a loss of ground strap life. VDA film removal now occurs
at ~300 bursts. When the capacitance is increased to 100×10^{-9} F, the film
removal occurs after ~20 bursts. These results are given in Ftgure 5. Visible
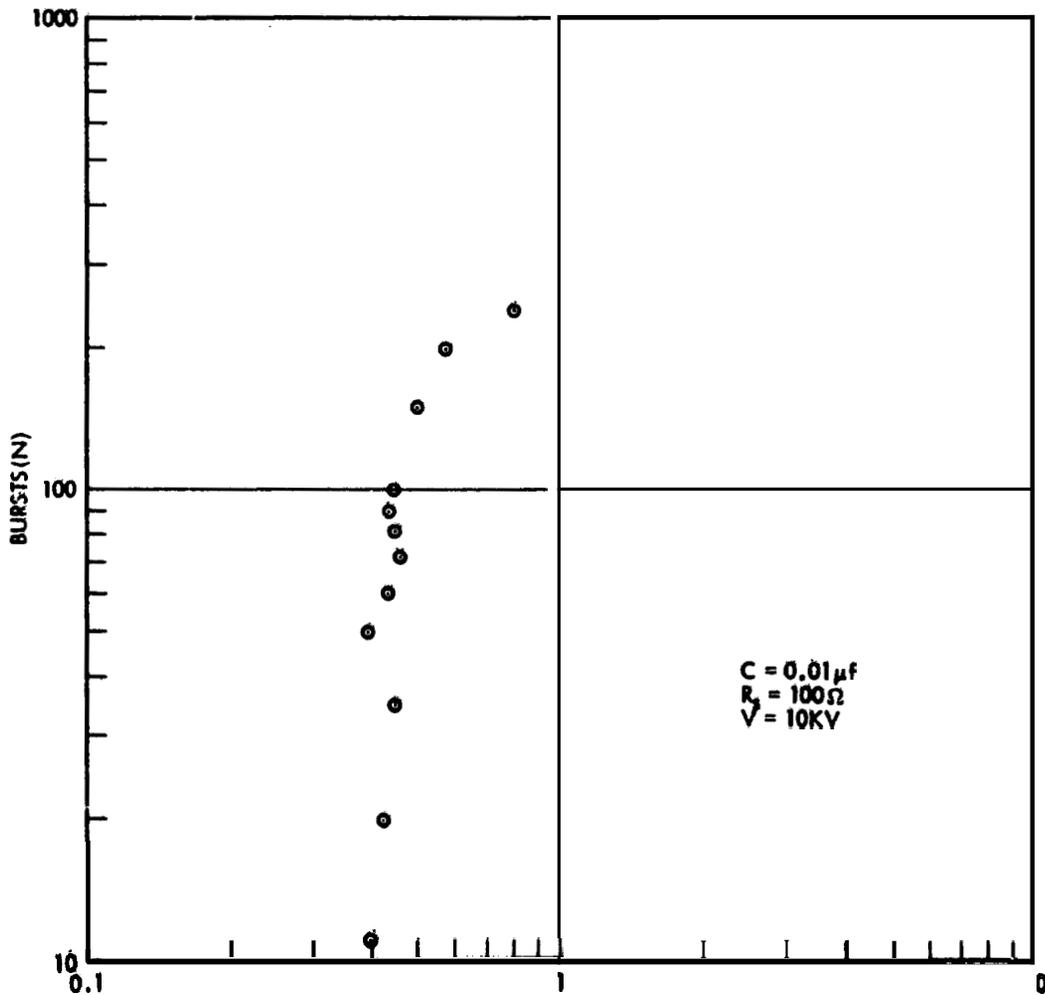surface arcs were not observed for these higher capacitance discharges, following

Figure 9. Resistance of VDA/NOMEX/Groundstrap Sample 3 as a Function
of the Number of Curredt Bursts. Initial surge curreht = 100 A and total
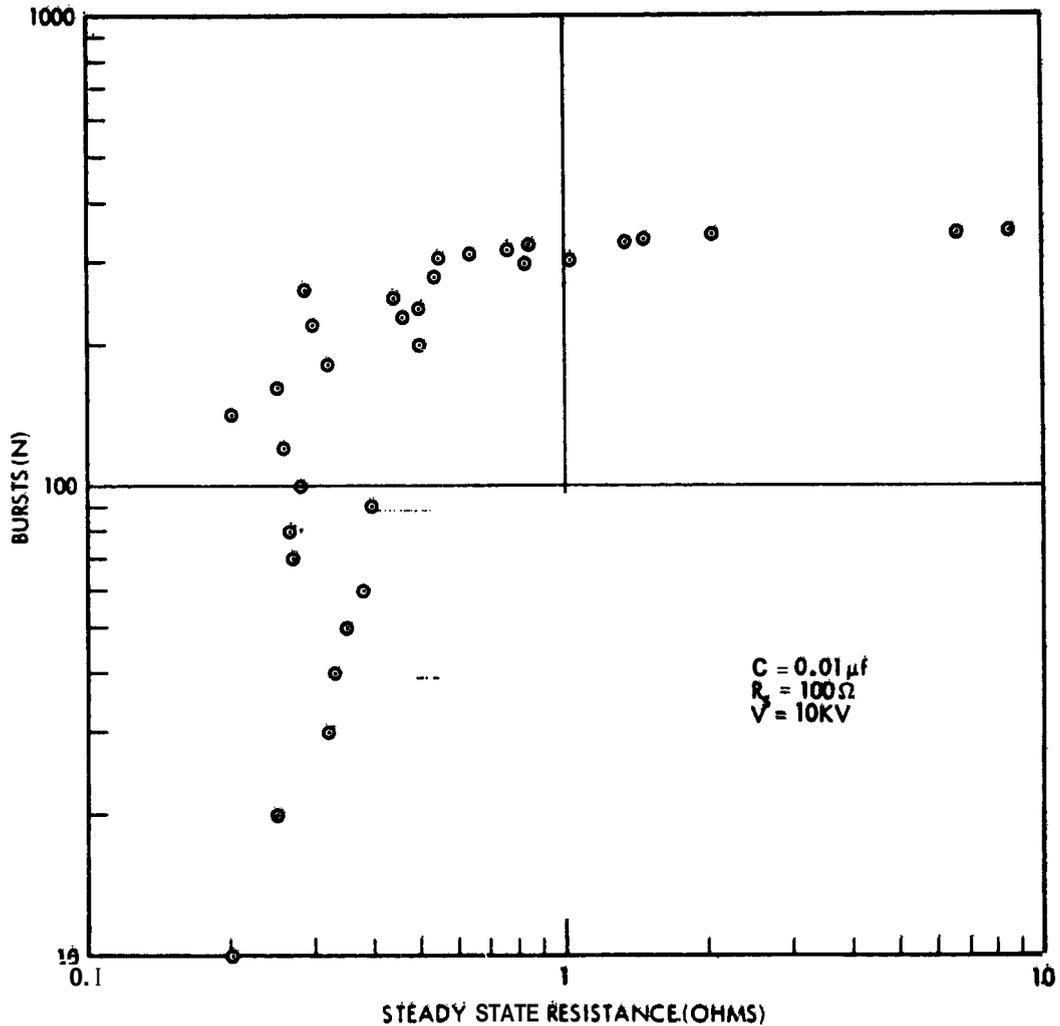charge throughput = 100 μc

Figure 4. Resistance of VDA /NOMEX/Groundstrap Sample 4 as a Function of the Number of Current Bursts. Initial surge current = 100 A and total charge thrbughput = 100 μc

lose of VDA and the increase in the eteady state resistance. The loss of allowable buret number befbre VDA removal With increasing capacitance Is expected to occur and had been observed previously in the ground strap experiments of Hoffmaster et al 1 (see, for example, Figure 9, of Hoffmaster[1]). The most significant feature, however, for this newer configuration is a conduction ability after VDA removal and wtthbut surface breakdown.
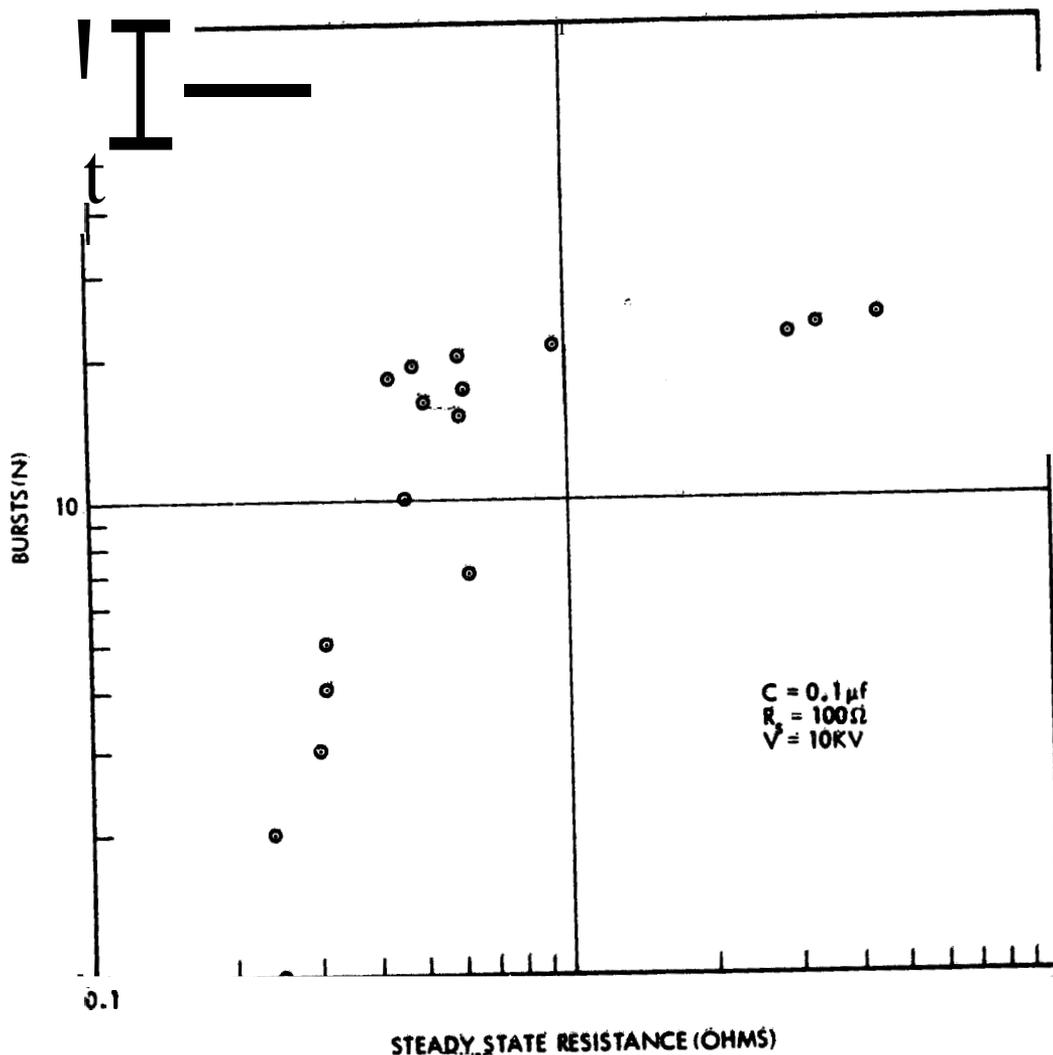
Figure 5. Resistance of VDA/NOMEX/Groundstrap Sample 5 as a Function of the Number of current Bursts. Initial surge current = 100 A and total charge throughput = 1000 μc

3.3 Dynamic Resistance

The dynamic resistance measufemente are obtained by meaeured current flow in the circuit and the accompanying clamp-tb-clamp voltage during the current burst. This dynamic resistance will not be equal to the steady state resistance, in general, and, also of importance, will not remain at the dame value during the current buret. TO illustrate the differences between steady state and dynamic

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resistances, this section Will contain measurements of both, although **principal emphasis will** be **on** resistance during the current burst.

For these measurements, a fresh sample, (Sample No. 6), was examined for both steady state and dynamic values as a function of burst number and as a function of time during the current burst. Figures 6 − 9 have the results of these measurements. In Figure 6, the conventional, steady state, resistance is given. For a capacitance of 10,000 pF, 10^4 volts, and 100 Ω in series resistance, this sample withstood in excess of 400 burets before exhibiting a deterioration of the VDA film. Excess of 900 bursts were required to reach high level steady state resistance.

The dynamic resistance was measured at three time periods, 0.33 μsec, 0.94 μsec, and 2.5 μsec after the initiation of the current burst (Figures 7 − 9). Two effects are apparent. The first of these is a diminution of dynamic resistance for later periods in the burst conductions, and is evidence in a change in the surface material properties. The second effect is that dynamic resistance proceeds to values significantly less than the post burst steady state resistance.

The exact nature of the surface change taking place during the burst has not been determined. There is no visible surface arc. There is, nevertheless, some surface (or perhaps NOMEX) alteration which provides an increasingly effective conduction path for current, for increased flow duration, and which acts, after the VDA removal, as an effective, alternate, conduction path.
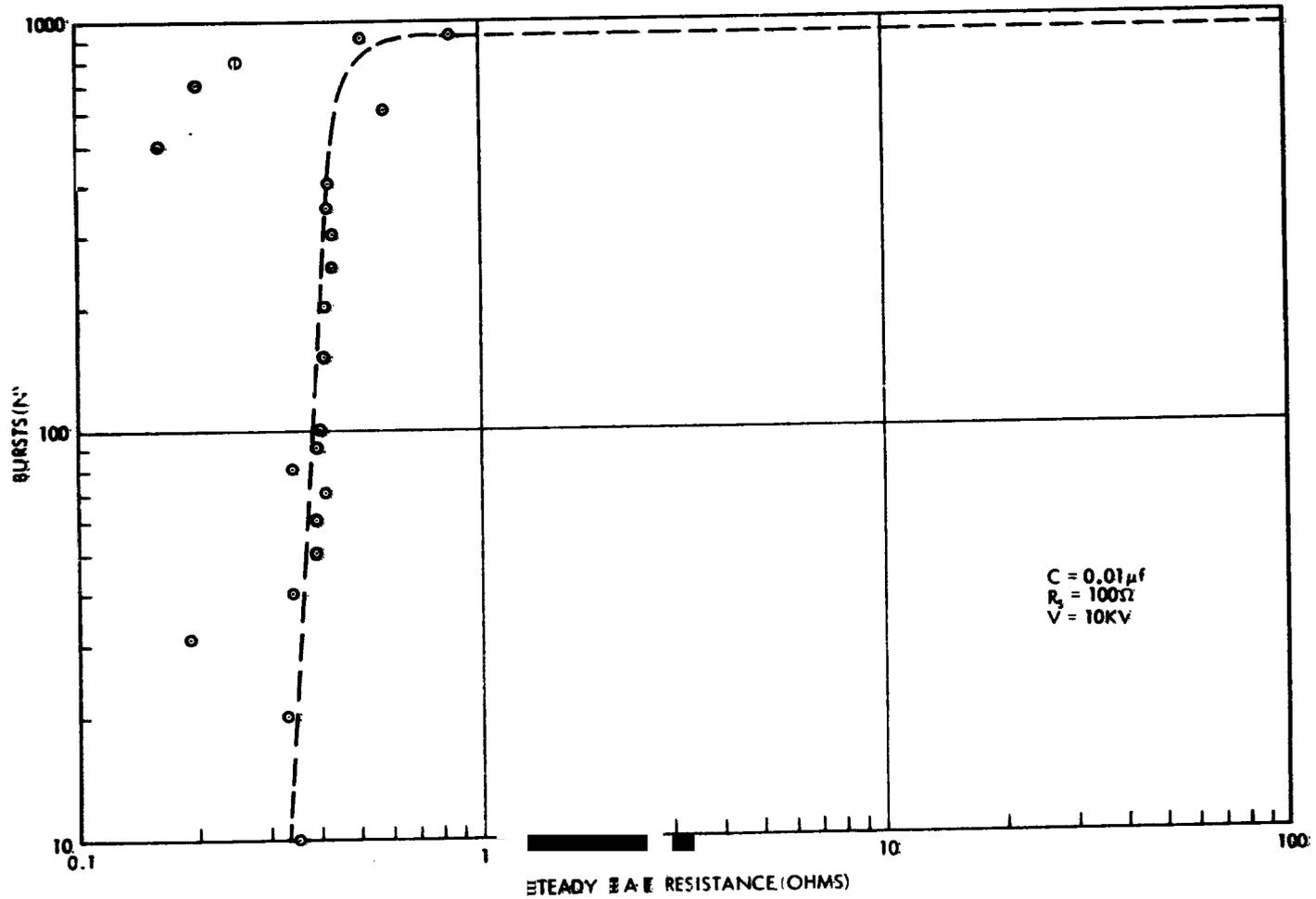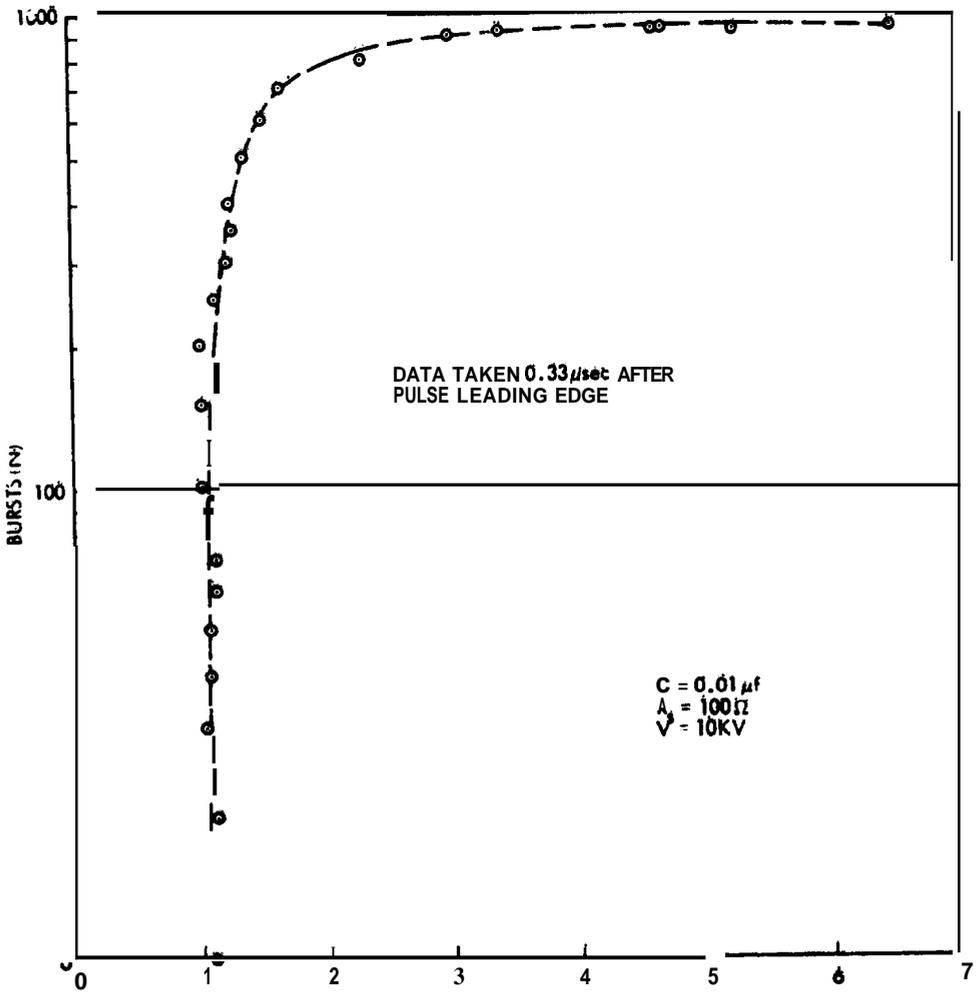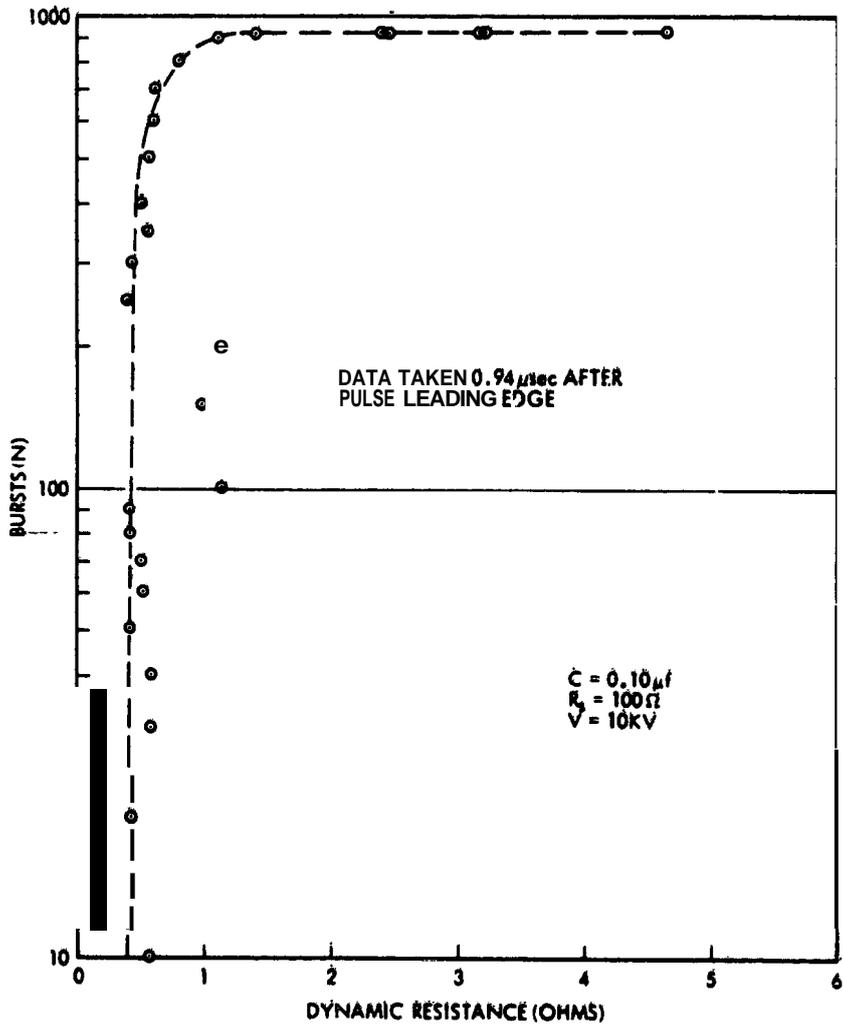
Figure 6. Resistance of VDA/NOMEX/Groundstrap Sample 6 as a Function of the Number of Current Bursts. Initial surge current = 100 A and total charge throughput = 100 μc

DATA TAKEN 0.33 μsec AFTER
PULSE LEADING EDGE

C = 0.01 μf
A = 100 Ω
V = 10KV

Figure 8. Dynamic Resistance of VDA/NOMEX/Groundstrap Sample 6 as a Function of the Number of Current Bursts at 0.94 μsec after Current Surge Initiation

DATA TAKEN 2.5 μsec AFTER PULSE LEADING EDGE

$C = 0.01 \mu f$
$R_s = 100 \Omega$
$V = 10KV$

Figure 9.   Dynamic Resistance of VDA /NOMEX/Groundstrap Sample 6 as a Function of the Number of Current Bursts at 2. 5 μsec after Current Surge Initiation
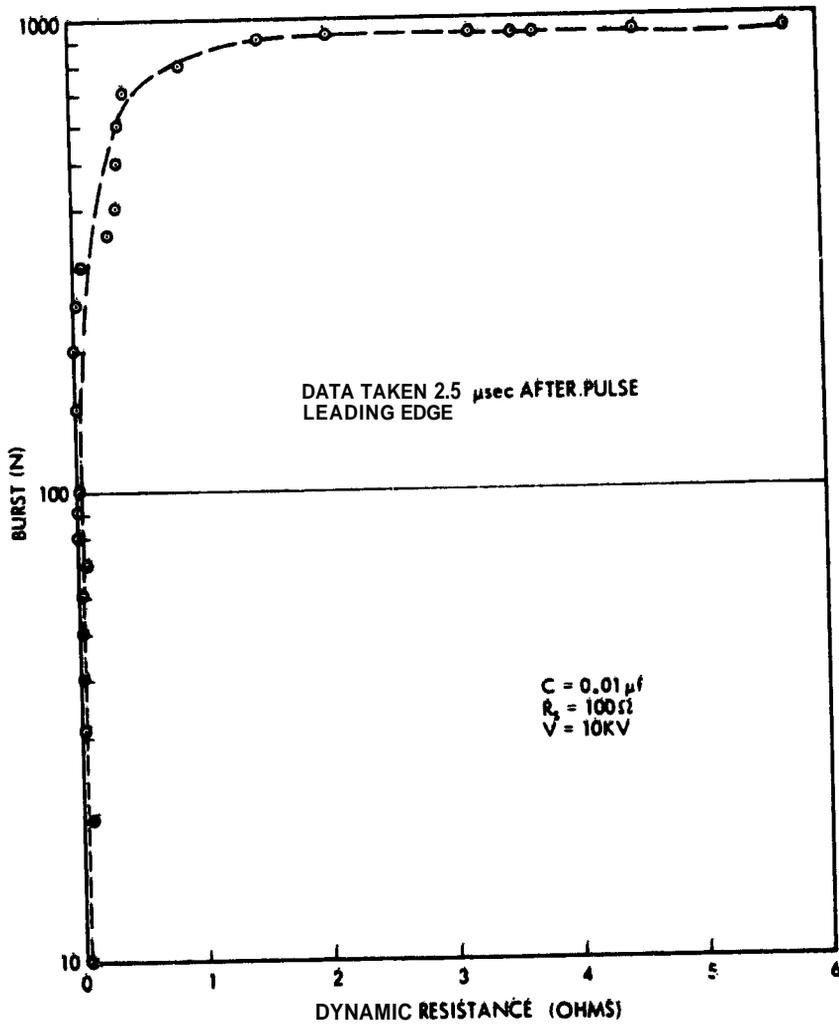
4. ELECTRON SWARM TUNNEL TESTS

4.1 General Considerations

The results of the current surge teats indicated that the presence of the NOMEX grid on the rear face aids in conduction bf these large current bursts. In the process of-grid attachment, however, it appeared as a possibility that the NOMEX grid could cause a field Intensification for electrorl cbnduction through the bulk bf the Kapton film which could (possibly) result in dielectric-to-metal arcs from the Kapton ihterior to the rear Pace VDA for severe charge-up on the Kaptbn surfafe. The Electron Swarm Tunnel (EST) tests were initiateu to explore this sefond, and important, charge conduction process.

The EST used for these tests is the 2 ft X 4 ft facility described earlier in Hoffmaster and Sellen.[1] I· this chamber, a monoetiergetic electrod beam streams along the chamber axis and deposits bn the exteribr face of the dielectric film, thus simulating the-electrbn depbsition process during magnetic substorms in space. In the 2 ft X 4 ft EST, both electron flus and electron energy are variable. Although light sources are present in this facility, there was no deliberate application of light during the electroh deposition, and, thus, no deliberate appeal to photo conductive transport of deposited electrons through the foil. Ih the depositton tests to be discussed here, electron acceleration energy varied frbm 2 to 6 kV and deposition flux from 10 nA/cm² to 20 nA/cm².

4.2 Sample Configuration

Figure 16 illustrates the sample configuration used in the EST tests. The measured drainage current is at the rear face VDA film for forward face electron deposition. The added ring on the front surface (with overlying insulating films) acts as a guard ring to prevent Burface drainage current entrance into the rear face VDA film. The resulting measurements are, thus, of bulk conduction currents in the Kapton as a result of the depositton of energetic electrons on the front surface of the film.

4.3 Electron Drainage Current Measurements

4.3.1 DRAINAGE THROUGH KAPTON A T 0.0005 IN. THICKNESS

Figure 11 illustrates the drainage current density (ih hahoampéres per square: centimeter) as a function of the acceleration voltage of the deposited electrons and for varying levels of electron flus in the depositidn. The order in whlch the exposures Have been made is sigñificant.

The initial depositton condition was a 2 keV electron flow at 10 nA/cm², leading to a rear face drainage current df ~ 0.05 nA/cm². This drainage current is
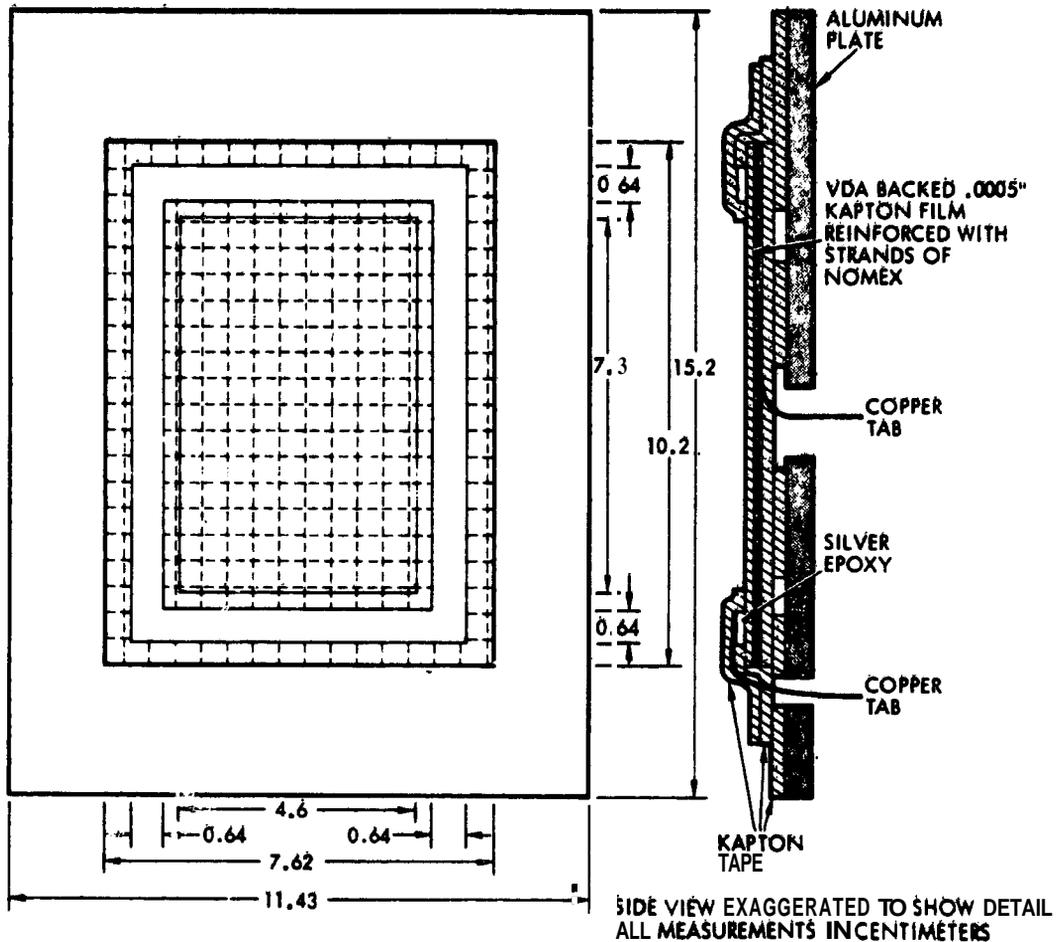
Figure 10. Kapton/VDA/NOMEX Thermal Control Material Sample Configu-
ration for Electron Swarm Tunnel 'rests

considerably larger then that observed for 0. 002 in. $(5 \times 10^{-3}$ cm) Kapton foil,
measured earlier. Larger drainage is expected, of course, because of the re-
duced thickness $(1.27 \times 10^{-3}$ cm) of the foil.

Increases in beatn energy to 4 keV caused drainage current density to increase
to ~0. 5 nA/cm^2. This rapid increase in conduction current density as beam
energy increased is typical, and is attributed to field enhahced conductivity in the
material. A continued increase in electron accelerntian ehergy to 6 keV, caused
ah increase in conduction current to 1.5 nA/cm^2. Since the incident flux at this
point was only 10 nA/cm^2, and stnce secondary electron emission causes a
rerelease, back to space, of significant amounts of electrohs, the observed
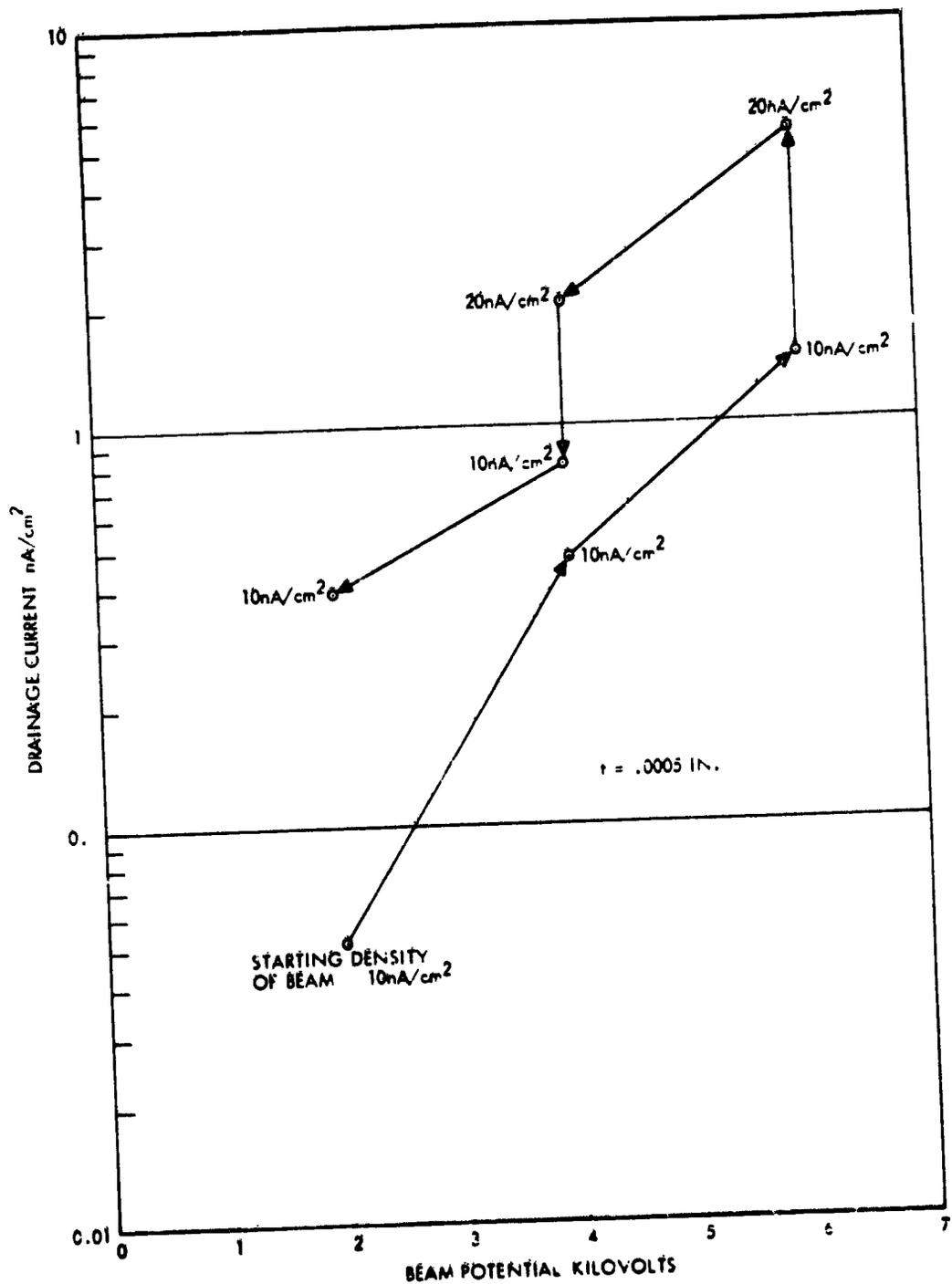
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Figure 11. Electron Drainage Current Density as a Function of Electron Beam Acceleration Voltage for Deposition Flux Densities of 10 nA/cm^2 and 20 nA/ cm^2 on ORCON Utilizing 0.0005 in. Kapton Base Film

conductton could be limited by incident flux rather than by material resistivity. To test this possibility, the deposition flux was increased from $10 \, nA/cm^2$ to $20 \, nA/cm^2$ and conductton current density increased from 1.5 to 5.4 nA/cm^2 thus confirming notions of conduction limited to incident deposition.

These extraordinary drainage levels (in excess of substorm depositions) usually lead to materlal alteration. To examine the possibility of permanent alteration, the deposition conditions were then moved to (4 keV, $20 \, nA/cm^2$) to (4 keV, $10 \, nA/cm^2$) and, finally, to (2 keV, $10 \, nA/cm^2$). The evidence clearly demonstrates that a permanent alteration of the material has occurred as a result of the high level drainage at the upper end point of the acceleration voltages applied

The drainage curfent measurements also examined the conduction current trace for evidence of material electrical breakdown. Although occasional alterations of drainage curr.nt were observed, there were no major interruptions At the conclusion of the drainage current tests, the sample was removed from the test chamber and subjected to visual and microscopic examination. 'here was no evidence of electrical breakdown. Thls is not to conclude that optical properties (absorptivity, emissivity) of the Kapton film have remained unaltered by the high electric stress electron drainage conduction. Measurement of optical properties should be carried out both before and after the electron deposition to determine if film alteration has occurred.

4.3.2 DRAINAGE THROUGH KAPTON AT 0.003 IN. THICKNESS

Section **1** has noted that the ultimate selection of spacecraft surface materials will involve many different features of the materials. Mechanical strength of the base film is amongst those features. At the conclusion of the tests with the 0.**0005** in. Kapton film sample described in the sections above, and concurrent with the availability for test of a material similar to the first sample (NOMEX grid and **VDA** features unchanged) but with **0.**003 in. thick Kapton as the base film, it was cansiderbd of interest to repeat the current conduction tests. The surge current conduction behavior would not appear likely to be dependent upon the base film thickness, because these surge currents are within the **VDA** film and the NOMEX fibers. There was no apparent reason, thus, for a repetition of the surge current cohduction for the ORCON film utilizing the thicker Kapton **as** the base film **The** bulk conduction of electrons through the film in the EST tests, on the other hand, could be expected to be thickness dependent, and these electron deposition experiments were repeated with the new, thicker film, samples.

The 0.003 in. Kapton film ORCON sample construction was the same as that illustrated in Figure **10,** except that the Kapton film, **as** previously noted, is now 0.003 in. thick, and the lateral dimensions of the sample whose drainage is under examination are 7.**1** × **7.**1 cm (rather than the **4.**6 × **7.**3 dimensions used in the 0.0005 In. base film case).

The second ORCON sample was placed in the EST and the beam energy varied from 4 to 10 kV at current densities of 10 nA/cm^2 and 20 nA/cm^2. Figure 12 illustrates the measured conduction current in this sample with the thicker Kapton film. Several features of the results shown there differ considerably from the drainage current results shown in Figure 11 for the thinner Kapton. The major difference between the two films is that the drainage current density is greatly reduced for the thicker film, compared to the drainage of the 0.0005 in. sample. Under a conventional approach to this electron conduction it might be expected that drainage currents would be reduced by a factor of 6, because the film thickness increases by a factor of 6 (0.0005 in. to 0.0003 in.) and because film resistance in conventional conduction should be proportional to film thickness. It should be noted, however, that the conduction is reduced by ratios much larger than the thickness ratio. At 4 keV, 10 nA/cm^2 conditions the drainage current densities are ~0.5 nA/cm^2 for the thin material and 0.009 nA/cm^2 for the thicker material. At 6 keV, 10 nA/cm^2 conditions, the respective drainage current densities are 1.5 nA/cm^2 and 0.025 nA/cm^2. The ratio of the drainage current densities at 4 keV is 55 and at 6 keV is 60, which in both instances is very much larger than the thickness ratio of 6.

The marked drop in electron drainage as material thickness t increases, appears to be the result of field dependent bulk resistivity. It has been previously noted in these drainage experiments that bulk resistivity is clearly nonconstant for electric stress values above some critical upper bound. The field point at which conduction increases rapidly is considered to be near 10^5 V/cm. For the thinner film this condition is attained for ~125 Volts from one face of the film to the other. For the thicker film, AV ~10^3 volts, before the 10^5 V/cm point is attained. For E 7 10^5 V/cm, the bulk resistivity appears to decline as exp {-K$\sqrt{E}$}, possibly as the result of Poole-Frenkel effect. Irrespective of the exact cause of the extra conduction, however, it should be emphasized that the thinner film has a much larger electric stress as a result of e-beam deposition than for the thicker film, and, hence, will conduct substantially larger drainage currents.

A second major difference between the behavior of the two sample thicknesses is in the permanent material alteration observed for the thinner film as a result of the e-beam exposure, while the thicker Kapton sample returns to the same drainage level when the e-beam deposition conditions are returned to earlier voltage and flux levels (the order of exposure for the thicker film was 4 keV, 10 nA/cm^2; 6 keV, 10 nA/cm^2; 8 keV, 10 nA/cm^2; 16 keV, 10 nA/cm^2; 10 keV/20 na/cm^2; 8 keV, 26 nA/cm^2; 6 keV, 20 nA/cm^2; and 6 keV, 10 nA/cm^2). The "closure" experiment at 6 keV 10 nA/cm^2 revealed no permanent material change for the thicker sample, while the thinner sample exhibited almost one order of magnitude
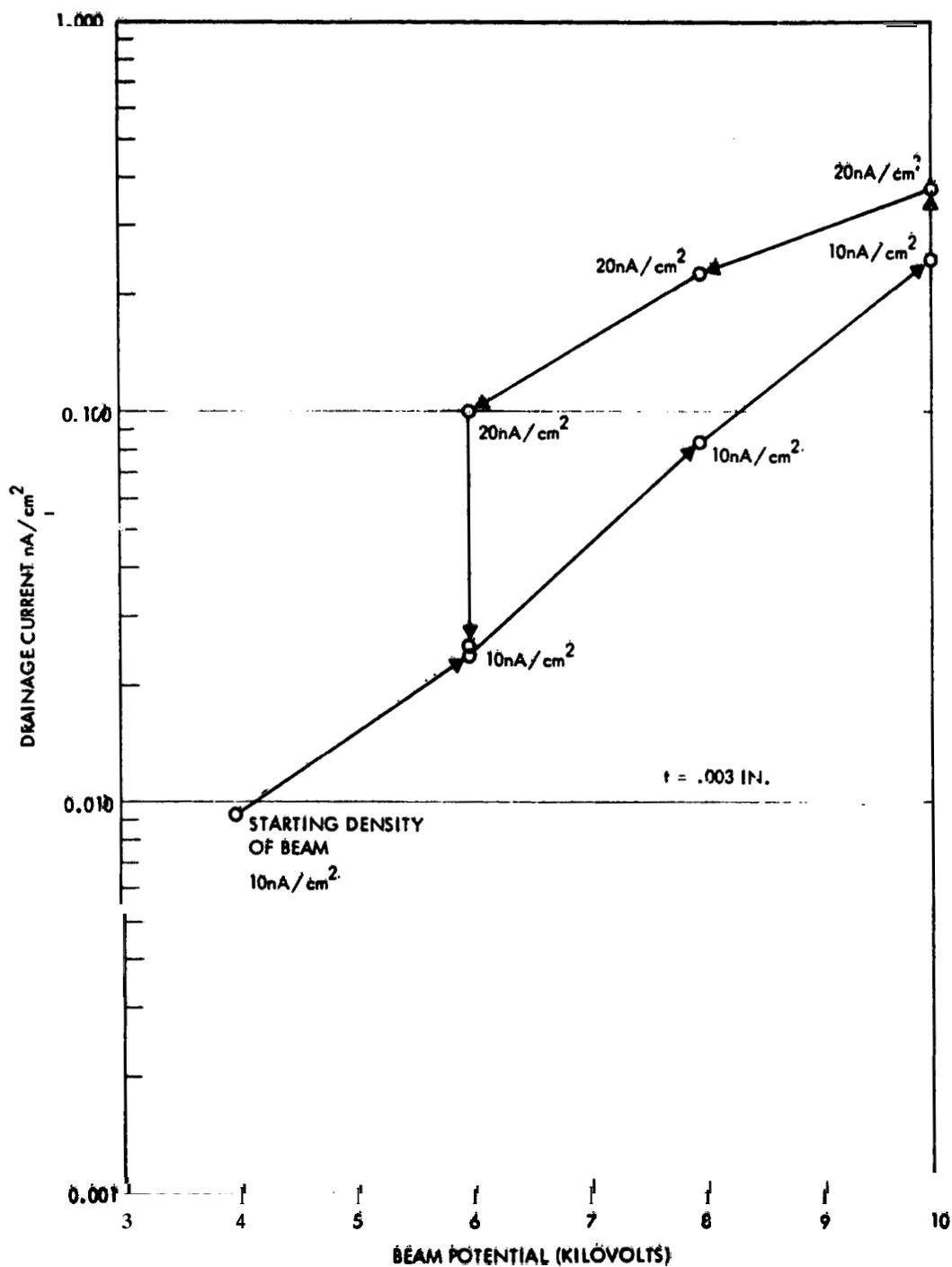
Figure 12. Electron Drainage Current Density as a Function of Electron Beam Acceleration Voltage for Deposition Flux Densities of 10 nA/cm^2 and 20 nA/cm^2 on ORCON Utilizing 0.603 in. Kapton Base Film

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change from its two 2 keV, 10 nA/cm^2 exposures, and a factor of approximately 2 at the 4 keV, 10 nA/cm^2 conditions (see Figure 11).

From the results given in Figures 11 and 12 it is apparent that the thinner material has much higher drainage currents than the thicker material, and that permanent alteration has taken place in the thinner material. Theee results are encouraging from the standpoint of the use of the 0.003 in. Kapton. A remaining question is the possible occurrence of dielectric-to-metal arcs in the thicker material. To monitor the possible occurrence of such breakdowns in the film, the drainage currents were continuously displayed on Chart recorders. There was no evidence of material breakdown in the recorded drainage current traces. Following the e-beam teets, the sample was removed from the test chamber and visually examined for pinhole breakthroughs. There was do visible evidence that any such breakthroughs had occurred. Measurements of α and ϵ were not carried out and should be included in future e-beam deposition tests. From the present evidence it would appear that permanent alteration in the material did not occur, either in observed drainage currents of: in visible punch-throughs.

5. SUMMARY AND RECOMMENDATIONS

The response of the rear face VDA film/NOMEX/ground strap configuration to surge currents has been ekamined and found to be superior to that of earlier VDA/ground straps. More bursts arc! allowed before ground strap resistance begins its sharp rise, and, even after the removal of the VDA, conduction occurs (presumably through the NOMEX) without surface breakdowns.

The forward face Kapton layer of the 0.0005 in. ORCON material was expbsed to an EST beam ranging frbm 2 to 6 keV anti with fluxes of 10 nA/cm^2 and 20 nA/cm^2. Drainage currents were large and increased with continued exposure to the electron deposition, indicating a material change. There was no evidence, however, of dielectric to metal arcs. There were no measurements of surface absorptivity or emissivity, so there is no way of determining at present if these quantities altered as a result of the electron deposition. These measurements should be carried out. The forward face Kapton layer of a 0.003 in. ORCON material was also exposed to an EST beam. For this material the beam energy ranged from 4 to 16 keV. The observed drainage currents were greatly reduced compared to the thinner Kapton film. There was no evidence of permanent film alteration in the bulk conduction as a result of the e-beam deposition, and examination of the drainage current traces and visual examination of the sample failed to reveal any evidence of dielectric to metal arcs.

The behavior of this material was generally superior to that of previous film/bonding/ground strap configurations in the surge current tests. In the electron drainage measurements of bulk conduction, the 0.003 in. Kapton sample was considerably superior in performance to that of the 0.0005 in. thickness sample. From the results of these measurements the use of the NOMEX grid backing is indicated as desirable and the thickness of Kapton should be the 0.003 in. case rather than the 0.0005 in. material.

References

1. Hoffmaster, D.K., Komatsu, G.K., Roy, N.L., and Sellen, J.M., Jr. (1974) Surge Current Conduction in Vacuum Deposited Aluminum Films Bnd bonded Aluminum Ground Straps, TRW 4351.3.74-34.
2. Hoffmaster, D.K., and Sellen, J.M., Jr. (1974) Electron Swarm Tunnel Measurements of Kapton Bulk Resistivity at High Electric Stress Levels, TRW 4351.3.74-59.