DESIGN OF AN ARC-FREE THERMAL BLANKET

Christakis N. Fellas
British Aerospace Public Limited Company
Space and Communications Division

SUMMARY

One way of dealing with the problem of spacecraft charging is to provide a thermal control surface which will not charge up to the breakdown level, while retaining its thermal control properties. A thermal blanket configuration meeting these requirements has been designed at British Aerospace (ref. 1).

Arcing is eliminated by limiting the surface potential to well below the threshold level for discharge. This is achieved by enhancing the leakage current which results in conduction of the excess charge to the spacecraft structure. The thermal blanket consists of several layers of thermal control (Space approved) materials, bonded together, with Kapton on the outside, arranged in such a way that when the outer surface is charged by electron irradiation, a strong electric field is set up on the outer Kapton layer resulting in a greatly improved conductivity.

This paper describes how the basic properties of matter were utilised in designing this blanket and how charge removal was achieved together with the optimum thermo-optical properties.

INTRODUCTION

When a surface is subject to electron bombardment, the important electron parameters are the electron energy and the flux. The electron energy determines the maximum surface voltage that may be attained, provided the target material has a thickness well in excess of the electron range in that material (ref. 1). The flux level, i.e. the current per unit area incident upon the surface determines the rate of charging dV/dt. This also depends on a number of other factors and is given by the equation

$$\frac{dV}{dt} = \frac{1}{C}\left(I_{inc} - \sum_j I_j\right) \tag{1}$$

where C is the capacity of the surface

I_{inc} is the incident current

$\sum_j I_j$ is the sum of all components of the removal current, given by

$$\sum_j I_j = I_{pr} + I_{ph} + I_{bs} + I_{sec} + I_l \quad (2)$$

where I_{pr} is the incident proton current

I_{ph} is the photo-electric effect induced current

I_{bs} is the back-scattering current

I_{sec} is the secondary electron current

and I_l is the leakage current through the dielectric material.

The design of an arc-free thermal blanket involves the enhancing of one of the removal currents, namely the leakage current, so that dV/dt becomes zero at a surface voltage potential well below that anticipated from the electron energy.

When the equilibrium surface voltage is below the discharge threshold for the entire range of electron energies anticipated, no discharges will occur. Thus an arc-free thermal blanket is obtained.

THE LEAKAGE CURRENT

In order to enhance the leakage current the parameters affecting its value are examined and one or more of these are varied accordingly. The leakage current may be considered as the sum of three components. The ohmic current, the internally induced secondary current and the transmission current. Thus we may write

$$I_l = I_{ohmic} + I_{insec} + I_{trans} \quad (3)$$

The ohmic current is the current which flows through the dielectric as a result of the existence of a potential difference across the material. In reference 1 an approximate expression is derived from classical mechanics for this term

$$I_{ohmic} \propto \exp\left(-\frac{\Delta W_j}{KT}\right) \sinh\left(\frac{V}{d} \cdot \frac{ea}{2KT}\right) \quad (4)$$

where ΔW_j is the ionization potential of the material

T is the absolute temperature

K is Boltzmann's Constant

V is the surface voltage

d is the material thickness

e is the electronic charge

and a is the average distance between atoms in the material.

The internal secondary current, referred to by other authors as "radiation induced conductivity", is the current resulting from the liberation of electrons from the atoms in the material by a process where energy from incoming electrons is transferred to material electrons. Although an analytical expression for this component has not been derived it is believed to be dependent on the electric field, the energy of the incident electrons and the flux of the incoming electrons.

The transmission current is the product of the electron transmission probability and the incoming current. The transmission probability P, for a simplified square wave potential is given by (ref. 1)

$$P \simeq \exp(-2b'd) \tag{5}$$

where d is the material thickness

and b' is given by

$$b'^2 = \frac{2m_e}{\hbar^2}(V_o - T_o) \tag{6}$$

where m_e is the electronic mass

$\hbar$ is Planck's Constant (divided by 2π)

V_o is the max. surface potential

and T_o is the kinetic energy of the incoming electrons.

The expressions given by equations (4) and (5) show that the leakage current is dependent exponentially upon the material thickness and consequently a decrease in thickness will lead to a much increased leakage current. In the case of a thin aluminised Kapton sheet, provided the aluminium layer is grounded a decrease in the material thickness will also lead to an increase electric field and this will influence the migration of charges deposited within the material to the aluminium layer. The electric field results from very low energy electrons, with near zero range, depositing their charge on the surface of the material.

As can be seen from equations (4) and (5) when the material thickness is decreased the relative proportion of the constituent currents of I_1 given in equation (3) change, so that for d=o, $I_1 = I_{tran} = I_{inc}$ and the surface voltage is zero. When the material thickness has a finite value the ohmic current and the internal secondary current have a non zero value provided there are sufficient low energy electrons to build up a voltage on the surface.

This may lead to a leakage current in excess of the incident current and such currents have been observed experimentally (ref. 1 and 2).

THE MULTILAYER THERMAL BLANKET

The thickness of the material determines the thermo-optical properties, so that a decrease in thickness reduces both the absorptivity α and the emissivity ε of the material. In general the ratio α/ε, which is a figure of merit for thermal control materials, increases with decreased thickness. For a 3 mil aluminised Kapton for instance $\alpha/\varepsilon = 0.538$ whilst for a 0.25 mil Kapton this figure becomes 0.688.

Another reason why a super thin dielectric film cannot be used as a thermal blanket is the mechanical properties of such film. The material must be sufficiently strong to withstand the testing environment. Thus for a Kapton film a thickness value of less than 2 mil is not considered practicable.

In order to overcome this problem, a multilayer thermal blanket (*) has been designed combining good mechanical strength, acceptable thermo-optical properties and the ability to conduct incident charge and keep the surface potential to well below the discharge threshold for the material. The prototype version is shown in figure 1. The outermost layer is a thin aluminised Kapton film. The thickness of 0.25 mil shown here is sufficient to keep the surface potential to below 2.5 KV at room temperature (or below 3.2 KV at -170°C) which is well below the discharge threshold of approximately 9 KV. The maximum potential value is obtained when the incident electrons have a mean range of approximately equal to 1/3 of the material thickness. For a 0.25 mil Kapton maximum surface potential is obtained with 7 KeV electrons. At higher energies the surface potential is reduced as the radiation induced conductivity is increased coupled with an enhanced diffusion process in the presence of a strong electric field and a shorter migration distance as the electrons are deposited closer to the charge collector.

The thermo-optical properties of this prototype multilayer thermal blanket are determined by the outermost layer, so for the configuration shown in figure 1 α/ε is 0.688.

The mechanical properties of the blanket are determined by the overall thickness of the blanket. The thicker (2 mil) aluminised Kapton is attached to the thinner aluminised layer by means of a double-sided pressure sensitive adhesive (e.g. Y966 PSA).

The thermo-optical properties of the configuration shown in figure 1 are limited by the thickness of the outermost layer. In order to overcome this the aluminium and the adhesive have been replaced by a single transparent conductive adhesive. This improved version is shown in figure 2.

(*) UK patent application No. 8035523 / USA application No. 204,703

A transparent conductive adhesive does not exist as such but it is possible to dilute a polyurethane based silver or cobalt loaded paint (e.g. Coballoy P212 *) and use it to attach the two layers of Kapton together. It is possible to spray a layer thin enough to be optically transparent but still retain enough conductivity for the multilayer principle to operate. A resistivity of 2 MΩ or less is believed to be sufficient.

An alternative to the use of conductive transparent adhesive is to use 0.25 mil Kapton spattered with Indium Tin Oxide and attach it to aluminised Kapton using a clear polyester adhesive. Such an arrangement is shown in figure 3. The advantage of this design is that the materials used are already qualified for Space use and the ITO spattered process on Kapton provides uniform reproducible properties on the inner conductive layer, which are difficult to achieve with a spray.

EXPERIMENTAL TESTS

The prototype multilayer thermal blanket of figure 1 has been extensively tested at the UKAEA electron Irradiation facility. The test results have been reported elsewhere (ref. 1).

Two samples of approximately 100 cm^2 were irradiated using monoenergetic electrons at 20°C and -170°C. The electron energy was varied from 3 to 30 kev at flux levels varying from 0.4 to 35 nA/cm^2. No discharges were observed at either temperature during six hour irradiation periods, under several different combinations of flux and energy. The maximum surface voltage recorded was 3.2 kV at -170°C with an incident electron energy of 7 kev and a flux of 24 nA/cm^2. The surface potential was substantially reduced at higher electron energies. The maximum surface potential at 20°C was 2.4 kV.

The tests described above prove the success of the design in eliminating arcing of a dielectric, while maintaining the good thermo-optical properties. The results obtained from measurements of the leakage current and surface voltage were in accordance with the theory used to design the blanket.

Samples described in figures 2 and 3 are currently being investigated and the results will be the subject of another publication.

CONCLUSIONS

The success of the multilayer thermal blanket in eliminating arcing indicates the validity of the design principles used. Placing a charge collector at a certain depth in the dielectric sets up a strong electric field, improving charge mobility towards the charge collector and enhancing the leakage current. The increase in the leakage current is sufficient to make $dV/dt = 0$ at surface voltage level well below the discharge threshold.

* Available from Graham Magnetics Inc., Texas, USA.

The same principle has been used to design thermo-optically improved versions with optically transparent charge collectors. This design has been applied to second surface mirrors as well and results of the investigations will be published in due course.

REFERENCES

1. Fellas C.N. : An Arc-Free Thermal Blanket for Spacecraft Use, IEEE 1980 Annual Conference on Nuclear and Space Radiation Effects, Transactions on Nuclear Science, Vol. NS-27, No. 6, December 1980, p. 1801 - 1809.

2. Staskus J.V. and Berkopec F.D., Proceedings of Spacecraft Charging Technology Conference 1978 (NASA Conference Publication 2071, AFGL-TR-79-0082) U.S. Air Force Academy Colorado Springs, Oct.-Nov. 1978, p. 457-484.

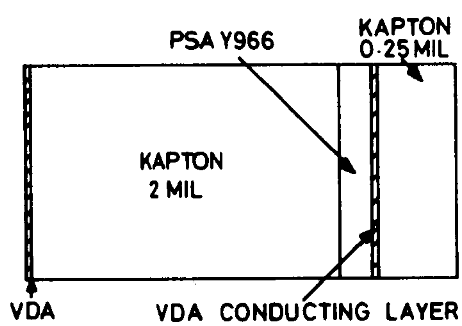

Figure 1. Prototype Version of the Multilayer Thermal Blanket.

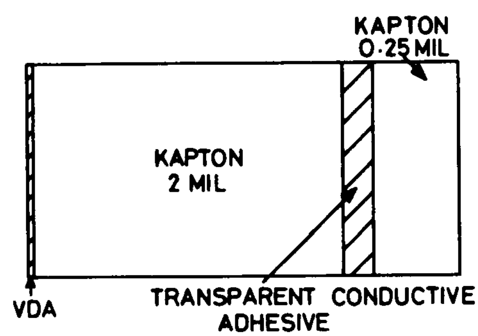

Figure 2. An Example of the Improved Version of the Multilayer Thermal Blanket.

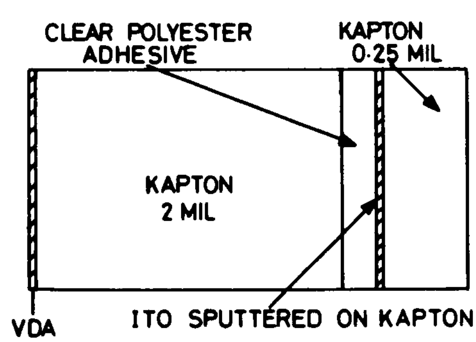

Figure 3. A Further Example of the Improved Version of the Multilayer Thermal Blanket.