N71-32483

NASA TECHNICAL MEMORANDUM

NASA TM X-67890

NASA TM X-67890

CASE FILE COPY

CURRENT DRAINAGE TO A HIGH VOLTAGE PROBE IN A DILUTE PLASMA

by Norman T. Grier & Daniel J. McKinzie, Jr.
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Tenth Aerospace Science Meeting sponsored by the
American Institute of Aeronautics and Astronautics
San Diego, California, January 17-19, 1972

CURRENT DRAINAGE TO A HIGH VOLTAGE PROBE

IN A DILUTE PLASMA

by Norman T. Grier & Daniel J. McKinzie, Jr.

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

E-6491

ABSTRACT

The current drainage from a plasma through approximately 0.05 cm diameter holes in Kapton H polymide film, FEP type C., and quartz microsheet placed on a probe at voltages up to 2000 volts d.c. have been determined both theoretically and experimentally. A Laplace field was used to numerically predict an upper limit for the drainage current. The measured current was less than the theoretical current for the FEP and quartz, and the two were approximately in agreement for Kapton H. The measured currents were on the order of 5 microamperes with the theoretical currents on the order of 10 microamperes.

INTRODUCTION

Solar cell arrays in the kilovolt range are being proposed for power generation on satellites. If the solar cell cover glass or the dielectric material insulating the connecting tabs between solar cells develop holes or cracks, a large drainage current from the ambient plasma may ensue resulting in degradation of performance. Cole, et al., (ref. 1) measured drainage current on the order of milliamperes through 0.0254 cm diameter holes in an Epoxy (resin Epon 828 with curing agent Epon V-40) and Kapton H polymide films when exposed to a plasma up to 3000 volts. All of their measurements were made directly in the exhaust of a Kaufman ion thruster. The ion velocity ($\sim$/8 km/sec) was, therefore, much higher than that found at orbital conditions in the ionosphere. This paper reports results for electron drainage current through known size holes in various dielectric materials. The dielectrics were placed in a pyrex bell attached to the side of a large vacuum tank which houses a Kaufman ion thruster generating an argon plasma. The specimens, therefore, were not located directly in the engine's exhaust beam. The plasma velocity was on the order of 4 km/sec, which is about half satellite velocity at 300 km altitude. The dielectric materials used were a quartz solar cell cover glass, Kapton H polymide film, and flourinated ethylene propelene (FEP) type C. The experimental results are compared with results calculated using a computer program developed by Parker (refs. 2, 3, 4, and 5).

Facility

The tests were performed in a 45.72 cm (18 in.) diameter by 76.2 cm (30 in.) long pyrex bell jar (fig. 1). The bell jar was mounted on a 61 cm (24 in.) diameter port located on the side of a 3.05 meter (10 ft) diameter by 4.57 meter (15 ft) long vacuum tank. The bell jar part's centerline was 2.29 meters (7-1/2 ft) from either end of the vacuum tank. The vacuum tank pressure was approximately 2×10^{-5} torr for all tests. The current test specimens were mounted on one end of a 3.2 cm diameter cylindrical pyrex sting. This passed through and was supported by an instrument ring attached to one end of the bell jar. The high voltage test location in the bell jar was approximately 2.03 meters from the centerline of the vacuum tank and 7.6 cm (3 in.) off the bell jar centerline. The ammeter used to measure the drainage current was located between the high voltage power supply and the test specimen. A sketch of the complete experimental set-up is shown in figure 1. The electrical connecting lines and ammeter were shielded with the shield at a potential of the test specimen. In all cases the high voltage probe was biased positively with respect to ground. The ion engine used to generate the argon test plasma was mounted on the center of one end cap of the vacuum tank.

Two cylindrical tungsten Langmuir probes and a Faraday cup were used to diagnose the plasma. One of the Langmuir probes (25.4 cm long by 0.0254 cm diameter) was located on the centerline of the tank at the axial station of the port to the bell jar. The other Langmuir probe (12.4 cm long by

0.0127 cm in diameter) was located in the bell jar approximately 20.32 cm (8 in.) front of the testing location. A 10.16 cm (4 in.) diameter Faraday cup was located about 25.4 cm (10 in.) inside the vacuum tank in front of the bell jar port. This cup was swung out of the port entrance during tests. The opening for the Faraday cup faced radially into the large vacuum tank.

Analysis

Ions enter the bell jar from the ion engine beam as a result of scattering collisions. The most probable process is charge exchange collisions with the neutral background gas. This process produces slow ions that can enter the bell jar. The velocity and number density of the ions in the bell were estimated as follows:

Velocity. - On a plane perpendicular to the axis of the tank at the axial position of the bell jar, the ion number density in the ion engine exhaust beam is larger than that in the bell jar. The largest ion density is on the centerline of the beam. A potential difference exists between the engine exhaust beam and the inside of the bell jar. This potential difference acclerates the charge exchange ions in the beam radially. Some of these enter the bell jar along with other scattered ions. The velocity of the ions was calculated from

$$\nu = \left(\frac{2e\Delta V}{M}\right)^{1/2} \tag{1}$$

where ΔV is the potential difference between the centerline of the ion engine plasma beam and the plasma potential (assumed constant) in the bell jar determined from the Langmuir probes measurements, and M the mass of the ions.

Number density. - The plasma number density in the bell jar was found by two independent means. The first method uses the current measured with the Faraday cup. The number density was calculated from the relation

$$n = \frac{I_F}{eA\nu} \tag{2}$$

where I_F is the Faraday cup current, e the electric charge, A the area of the Faraday cup, and v is the velocity of the ions from equation (1).

The second method used the Langmuir probe in the bell jar. For the electron densities expected in the bell jar and the beam, the Debye length is greater than the probe diameter, therefore, a thick sheath is expected about the Langmuir probe. According to electric probe theory (ref. 6), when there is a thick sheath surrounding cylindrical electric probes operating in the electron current saturated region and $eV >> kT$, the square of the current should vary linearly with the applied biased voltage. The number density is related to the slope of this curve by

$$n^2 = \frac{\pi^2}{2A^2e^2} \left(\frac{m}{e}\right) S \tag{3}$$

where S is the slope, A the probe area, m the electron mass, and e the electronic charge.

Computed Current

Two computer programs developed by Parker (ref. 3) were used to predict the current drainage through the holes in the dielectrics covering probes which are biased at high voltages relative to the plasma. One of the programs calculates the field distribution surrounding a planar probe by solving Laplace's equation numerically. Since the Laplace equation applies where there is no space charge, this implies the sheath or the electric field extends to infinity. The other computer program solves Vlasor's equation numerically for the current density when the electric field distribution is given. Parker (ref. 3) shows that Laplace fields give the maximum values for the current density for a given voltage on the probe. Therefore, the Laplace field was used to compute the maximum theoretical current through the holes in the dielectrics.

The Laplace field program calculates the field at preselected grid points surrounding an isolated cylinder with a planar probe embedded flush in the center of one of its ends. (See fig. 2.) Cylindrical coordinates are chosen such that the center of the probe has coordinates $z = 0$, $r = 0$ with the positive z-space above the probe. The size of the probe radius, the cylinder radius and height, grid boundary, and probe voltage, are input data. A dipole law is assumed for the potential between the grid boundary and infinity. In the calculations presented herein the following dimensions were used, probe radius 0.0254 cm (0.020 in. in diameter), cylinder radius 1.6 cm, cylinder height 3.0 cm, grid radius 50.0 cm, grid distance above cylinder (pos. z) 100 cm, and grid distance below cylinder (neg. z) 100 cm. The total number grid points used were 633 with 594 points in the positive z-space.

The current computer program utilizes the same geometry as the Laplace field computer program. Assuming a Maxwellian gas at infinity, this program numerically computes the current density ratio J/J_o at the center of the probe for a given field distribution, probe bias voltage, gas temperature at infinity, and directed velocity at infinity. J_o is the current density for zero bias voltage on the probe. It is given by

$$J_o = n \left(\frac{kT}{2\pi m}\right)^{1/2} \tag{4}$$

where n is the gas number density, T the temperature, and m the mass of the particles. In the tests, the kinetic energy gained by the particles from the probe voltage was much greater than the plasma free stream kinetic energy, therefore, the directed velocity was assumed zero in the calculations. However as a check on this assumption, a few cases were computed with a directed velocity of 5 km/sec. There were no changes in the results.

RESULTS AND DISCUSSION

Figures 3, 4, and 5 show the results for the Kapton H film, FEP type C, and quartz solar cell cover glass, respectively. The following values for the thickness, hole diameter, number density, and ΔV were used for each specimen.

Specimen	Thickness	Hole diam, cm	Potential difference	n, ions/cm^3
Quartz solar cell cover	0.0305	0.0516	1.73	1.4×10^6
Kapton H	0.0127	0.0508	1.40	1.7×10^6
FEP Type C	0.0127	0.0521	2.25	1.5×10^6

These number densities were determined using equation (3) from the experimental saturation electron current of the Langmuir probe in the bell jar. These number densities correspond to an altitude of approximately 300 kilometers. The electron temperature determined from the I-V characteristics of the probe was approximately 3000° K (≈0.3 eV). Since the range of probe potential V used was from +20 to +45 volts, eV was very much greater than kT in all cases, therefore, thick sheath electric probe theory applied. In determining the above number densities from the bell jar Langmuir probe, at least 12 values of the square of the current at applied bias voltages between +20 and +45 volts were fitted with a least square linear relation. This gave a root-mean-square deviation, for all points of less than 2 percent. These number densities determined from the Langmuir probe data were used in all the theoretical calculations. The values of number density listed above approximately agree with those determined from the Faraday cup.

For this study, the planar probe is considered to be simulated by the hole in the dielectric covering a metal disc. The results are shown in figures 3, 4, and 5. From the results presented in these figures, the computed current agrees within a factor of ±3 with that measured for Kapton H. It is larger ay approximately a factor of four for that obtained with FEP, and larger by approximately a factor of ten for the quartz measured current. The magnitude being on the order of microamperes. As previously stated, the current calculated using a Laplace field in the space surrounding the hole yeilds an upper current limit for a planar probe in a plasma. Therefore, the apparent agreement between theory and experiment for Kapton H is probably due to phenomena not considered in the theory. One phenomenon that may enhance the experimentally measured current is sputtering of the dielectric material. Sputtering produces a gas cloud near the hole. As some of the plasma electrons travel toward the hole, they make ionizing collisions with the gas cloud particles creating more electrons. These ejected electrons along with the original electrons now travel toward the hole, thereby, enhancing the measured current. If sputtering is enhancing the measured current, the results indicate that Kapton H is sputtered the most, FEP next, and quartz is sputtered the least.

Although the magnitude of the computed current differs from the measured current, the variation of the current with voltage is in agreement with experimental trend. This suggests that the theory may be used to estimate the drainage current at higher voltages than those presented here. However, it is expected that sputtering and other effects may become more severe at higher voltages for some materials.

CONCLUSIONS

Parker's method for calculating the current through holes in dielectric covering probes satisfactorily predicts the trends in experimentally measured current in dilute plasma for voltages up to 2000 volts. A Laplace field was used to numerically predict an upper limit for the drainage current. For holes in quartz and FEP, the theoretical current was larger than the measured current for all voltages presented. For Kapton H the theoretical current and the measured current were approximately in agreement over the full range of voltages presented. Since the computed current is the theoretical maximum current, this agreement suggests that other phenomena may be occurring near the hole enhancing the measured current.

REFERENCES

1. Cole, R. K., Ogawa, H. S., and Sellen, J. M., Jr., "Operation of Solar Cell Arrays in Dilute Streaming Plasmas" TRW-09357-6006-R000, NASA CR-72376, Mar. 15, 1968, TRW Systems, Redondo Beach, Calif.

2. Parker, L. W. and Whipple, E. C., Jr., "Theory of Spacecraft Sheath Structure, Potential, and Velocity Effects on Ion Measurements by Traps and Mass Spectrometers," Journal of Geophysical Research, Vol. 75, No. 25, Sept. 1, 1970, pp. 4720-4733.

3. Parker, L. W., "Theory of the Circular Planar (Guarding) Langmuir Probe," ERL 100 - AL2, Dec. 1968, ESSA, Boulder, Colo.

4. Parker, L. W., "Theory of Electrostatic Planar and Spherical Probes," CR-704, 1967, NASA, Washington, D.C.

5. Parker, L. W. and Whipple, E. C., Jr., "Theory of a Satellite Electrostatic Probe," Annals of Physics, Vol. 44, No. 1, Aug. 1967, pp. 126-161.

6. Chen, F. F., "Electric Probes," Plasma Diagnostic Techniques, R. H. Huddlestone and S. L. Leonard, eds., Academic Press, New York, 1965, pp. 113-200.

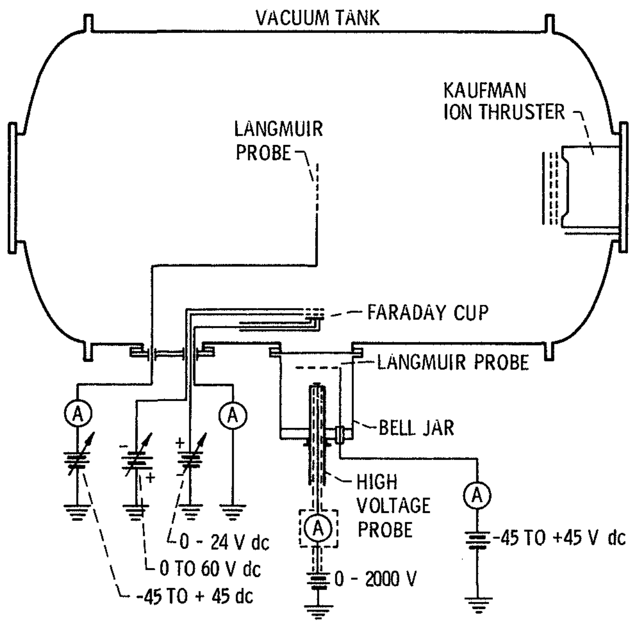

Figure 1. - Sketch of experimental facility. (Not to scale.)

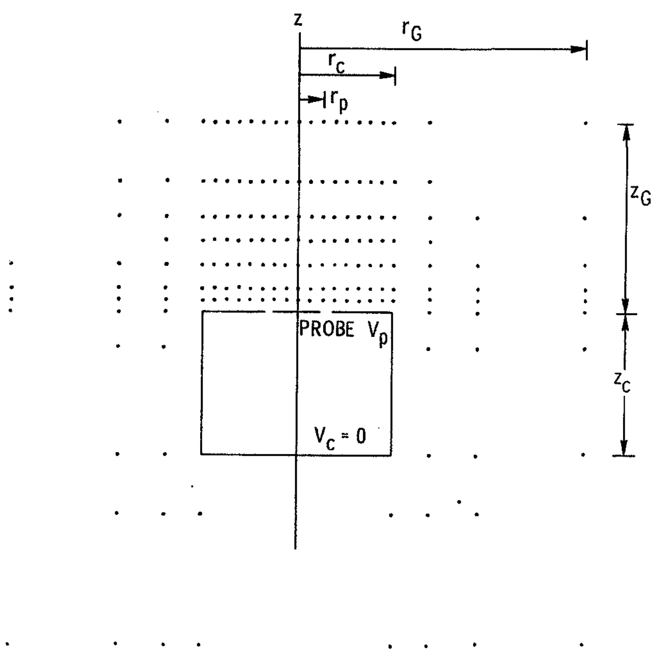

Figure 2. - Model for calculation: Closed cylindrical tube with a high potential probe embedded in one end.

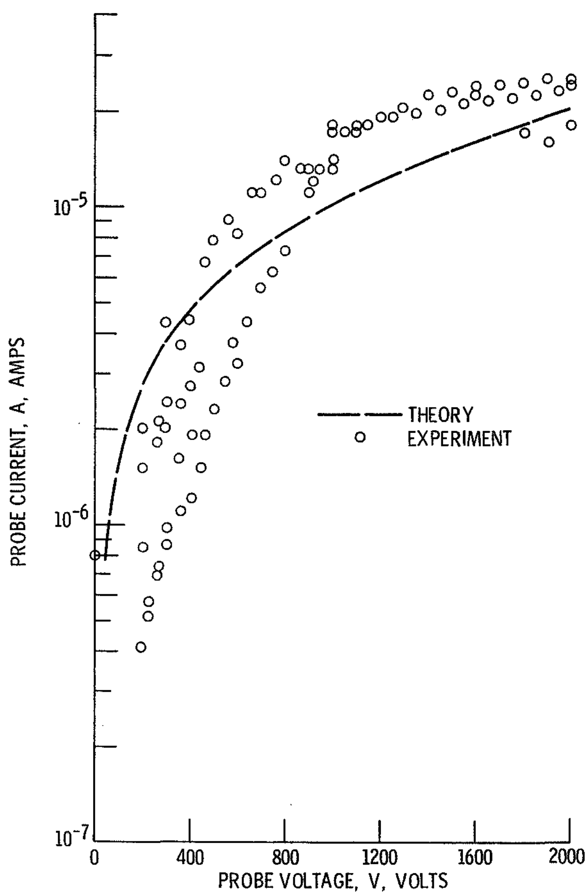

Figure 3. - Probe current as a function of probe voltage for 0.0508 centimeter diameter hole in Kapton H film.

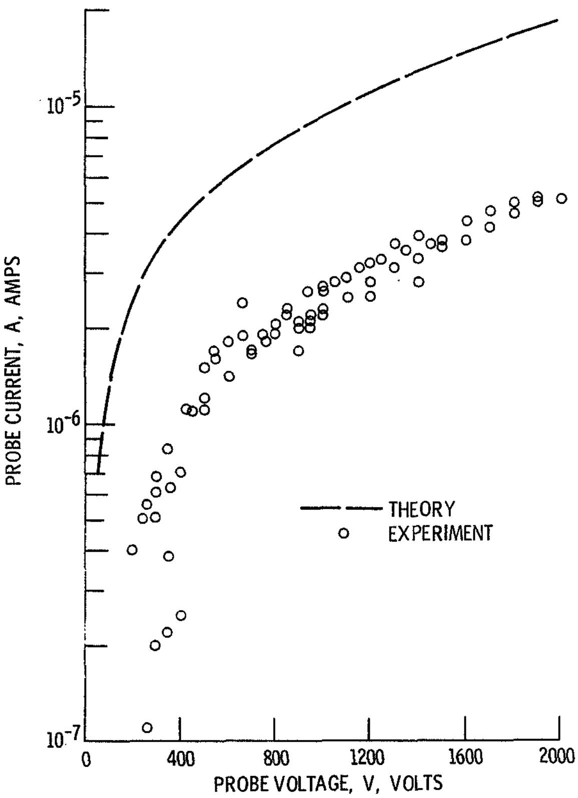

Figure 4. - Probe current as a function of probe voltage for 0.0521 centimeter diameter hole in FEP Type C.

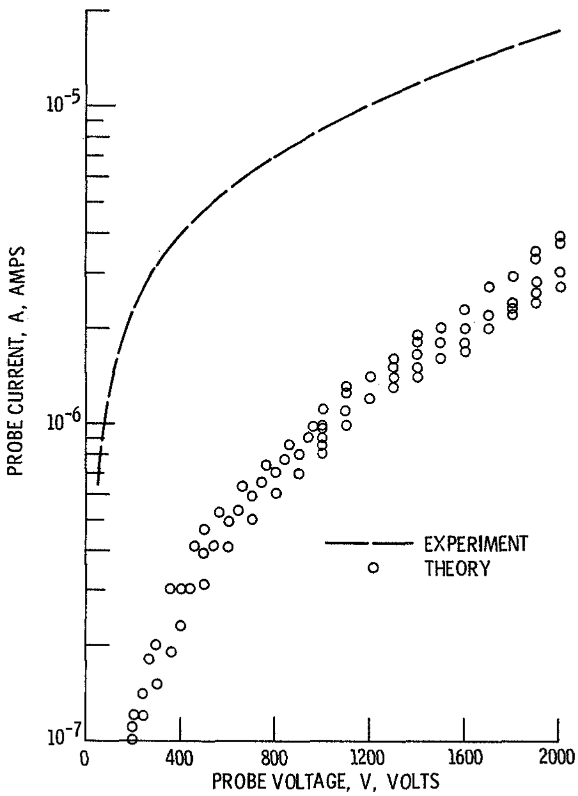

Figure 5. - Probe current as a function of probe voltage for 0.0516 centimeter diameter hole in quartz.