Contents

1. The Lewis Research Center Geomagnetic Substarm Simulation Facility

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Abstract

A simulation facility has been established at the NASA-Lewis Research Center tu determine the response of typical spacecraft materials to the geomagnetic sub-storm environment and to evaluate instrumentation that will be used tb monitor spacecraft syetem response to this environment. Space environment conditione simulated include the thermal-vacuum conditions of space, solar simulation, geo-magnetic substorm electron fluxes and energies, and the low energy plasma environment. Measurements for spacecraft material teats include sample currents, sample surface potentials, and the cumulative number of discharges. Discharge transients are measured by means of Current prbbes and oscilloscopes and are verified by a photomultiplier. Details of this facility and typical operating procedures &represented.

1. INTRODUCTION

Geosynchronous spacecraft have experienced anomalous electronic switching in the midnight-to-dawn region of their orbits.[1] **Environmental measurements**

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have shown that energies of transient particle flues ate higher than expected in this region.[2,3,4] Spacecraft anomalous behavior correlates well with the occurrence of geomagnetic substorms.[5,6] Differential charging of spacecraft surfaces can occur,[7] and breakdown of charged dielectric materials can follow. Breakdown can result in electromagnetic interference, degradation of thermal control surfaces, and surface contamination.[8]

A joint technology program has beeh implemented by NASA and the USAF to investigate the spacecraft charging phenomenon.[9] One objective of the joint program is to determine the charging behavior of spacecraft materials in a substorm environment and what effect configuration has on this behavior. This information will be used in future spacecraft design practice.

The approach to materials characterization is both experimental and analytical. The results of survey tests for a wide Variety of spacecraft surface materials have been summarized and have been published.[10-14] An analytical program has been developed in parallel with the experimental effort.[15] The experimental work ha8 been performed in a facility specifically developed to simulate the subatorm environment. 'his substorm Simulation facility is the subject of this paper.

2. FACILITY DESCRIPTION

The simulation facility Was developed to Characterize the behavior of spacecraft materials exposed to a simulation of the geomagnetic substorm environment. A schematic diagram of the spacecraft Charging test facility is presented in Figure 1.

2.1 Test Chamber

The facility test chamber is a stainless steel vacuum chamber 1.8 m in diameter and 1.8 m in length. A 1.5-m diameter thermal Control shroud lines the chamber interior. The shroud temperature is controlled by gaseous nitrogen which can be set to any temperature in the range from -185° to +120°C. The shroud is aluminum and is painted with a black electrically conductive paint providing a grounded boundary for all tests. The test chamber is pumped by a 6.9 m (36-in.) diameter oil diffusion pump and typically operates in the range from 6×10^{-8} to 2×10^{-7} torr. Pumpdown time is on the order of 90 to 120 minutes but generally testing is delayed until samples have sufficiently outgassed.

2.2 Simulation

The substorm environment is simulated in discrete increments. The aspect of the substorm environment that is of most intereat is the electron environment.

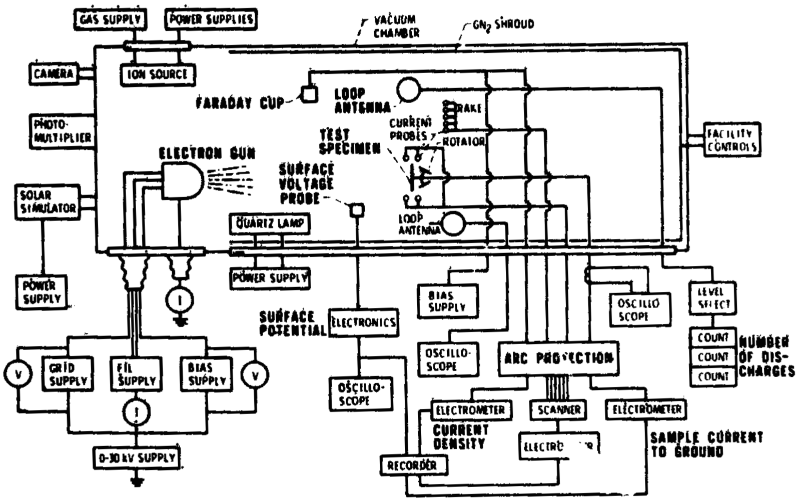

Figure 1. Schematic Diagram of the LeRC Substorm Simulation Facility

It is simulated with a Monoenergetic electron beam operated at a voltage in the range frdm 0 tb 30 kV and at a current density in the range from 0 to 5 nA/cm^2. The divergent electron beam id generated frbm a hot wire filament by means' of a spherical segment accelerating grid kept at ground potential. The cathbde and the beam-forming grids are biased negatively relative to this accelerating grid. The electron beam current density is uniform to about 36 percent over a diameter of 0.5 m at the test plane. The test plane is approximately 1 m from the accelerating grid.

Solar simulation is used When photoeffects are tb be determined. A 3/4-sun intensity xenun lamp is used; intensity is measured at the test plane. The solar simulator is located outside the chamber and the radiation. is passed through a quartz windbw. The spectral distribution, with the quartz window of the chamber, is within 10 percent of that recently published[16] for lolar radiation.

Low energy plasmas are simulated by means of si gaseous nitrogen electrbn bombardment plasma source. Nitrogen gas is admitted into a discharge chamber containing a hot wire filament cathode ahtl a cylindrical shell anode. A magnetic field coil is spirally wound around the anode to increase the path length of the bombarding. electrons from the cathode to the anode and thereby enhance the ioniza-tion efficiency. Plasma densities from about 10 particles per cm^3 up to 10^6 par-ticles per cm^3 can be simulated. The plasma source ts routinely used to discharge samples after testing.

2.3 Sample Accommodation

Figure **2 is** a photograph of the test chaniber interior. Samples tb be tested are mounted on a three-pasition dample rotator. Up to three different samples can thus be tested during each pumpdown of the facility. vacuum **can be** maiatained for several weeks for **survey** tests of three **samples.** Sample6 Up to 30 by **30** cm id **size** can be accommodated. The sample under test is located on the test chamber centerline **as** is the electron source. **The** electron source is mounted on the chamber door Seen partially on the right in Figure **2.**

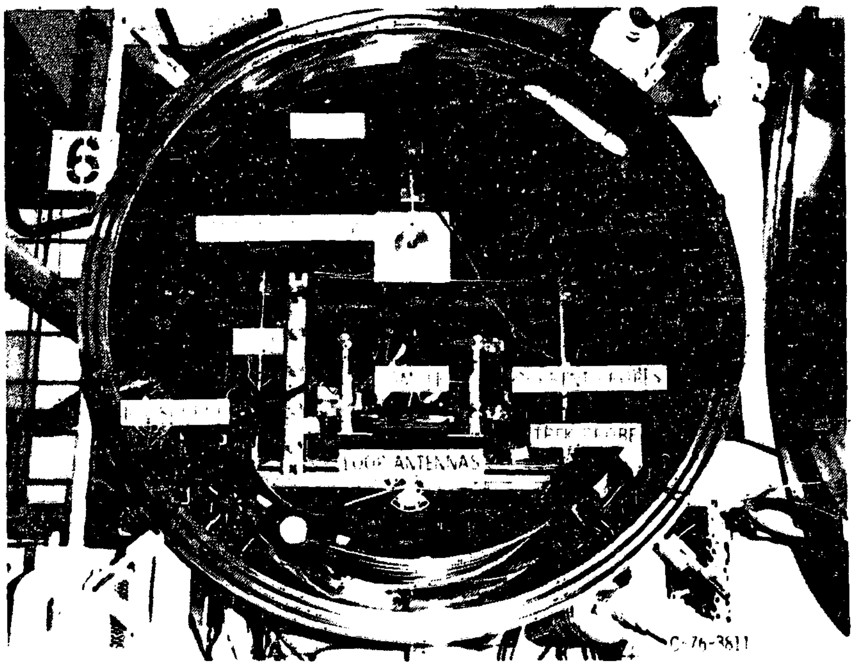

Figure **2.** LeRC Substorm Simulation Facility Test Chamber Interior

2.1 Instrumentation

2.4.1 ELECTRON ENVIRONMENT MEASUREMENTS

The electron curredt density at the test location is measured **with a** Faraday cup. The Faraday cup is mounted to a 30 by **30** cm metal pllte which Bhields the **test** sample. **The** Faraday cup-sample shield assembly is positioned in front of the sample only while the curredt density is being set. **The** edtrance area of the Faraday cup **is 10** cm^2. The suppression grid is operated at **-40 volts.** Stationary current probes are mounted around the sample. These probes are p'::.n metal disks, 5 cm^2 in area, that arb used to monitor the Current density e; the test plane throughout testing. The current density profile of the test plane is obtained by sweeping a rake of 5 current probes across the test.chamber. The Faraday cup, shield, stationary current probes, add rake can be seen in Figure 2.

2.4.2 SAMPLE MEASUREMENTS

Two basic measurements are made when a sample is Bubjected to the simulated substorm environment. The first of these is the sample elec'r'n current-to-ground. Samples are generally mounted on a metal plate substi . : with the dielectric surface facing the beam. During test the substrate is grounded through. an electrometer. The current through the sample is theh obtained as a function of time.

Sample surface potential is the second basic measurement made. Surface potential is meaeured by sweeping an electrobtatic voltmeter probe across the sample surface. The electrostatic voltmeter is a noncontacting capacitance Coupled device. The electrostatic voltmeter operates on a null balance principle whereby the surface potential, probe is brought to the potential of the sample surface by. a high voltage power supply. This design provides accurate meaeurement and minimizes voltage gradients in the measurement bcation. This measurement is made in the electroh beam. Since the probe add the sample are nearly the same potential, the prbbability of arcing between the prdbe and the surface under measurement is minimal. The response time of the device is *20* msec to Change 16 kV; this ib faster than typical chargidg times being measured. The probe-to-sample surface spacing is generally maintained at 2.5 mm; resolution is within 5 percent at this Bpacing for spots larger than 9 mm in diameter or strips wider than *6.5* mm.

When arc discharges occur, some additional data is taken. Loop antennas are used to sense and quantify discharge activity. The lbop antennas are 15 cm in diameter and the plane of the laop intersecte the plane of the sample! within the sample area.- The antenna-to-sample spacing is abbut 6.7 m. The signals received by the antennas are amplitude discriminated such that all sensed pulses of greater than several specific magnitudes are counted. The cumulative number of discharges of amplitude greater. than 1, 2.5, and 5 vblts, for example, at the input to the discrimination circuitry then become8 the basic discharge data. When discharges occur, the sample current measuring electrometer8 are shorted out bf the measurement circuitry and the sample current directly grounded. Inductively coupled current probes imd fast oscilloscopes (100 and 250 MHz) are used tb measure the arc-discharge currents. A photomultiplier tube is used to sense the visible emission portion df the discharges. The photomultiplier is also used to periodically verify the functioning of the discharge monitoring circuitry.

One of the most frequently used pieces of test chaniber apparatus is 8 Polaroid camera which is used to photograph discharges. Discharge lbcatiohs as well as some visual discharge characteristics are documented. Time exposures are made for varying periods, depending en the frequency of discharging.

3. TEST PROCEDURE

3.1 Initial Condition

Pridr to any testing, all instrumentation is calibrated. The test chamber is then evacuated to a pressure of less than 5×10^{-7} torr before any equipment is operated. Samples are generally maintained in vacuum for up to 16 hr before any high voltage testing is performed. Outgassing for this period has been found to be good practice. Before any testing is performed the sample surface potential is measured and discharged with the plaoma source. The state of the sample Burface is determined from measurements by the sample surface potential probe,

3.2 Establish Electron Substorm Conditions

"he electron beam is established by bringing the Faraday cup-shield assembly to its position in frbht of the sample shielding the Bample frbm the electron beam. The proper electron beam canditibns are then set. These conditions are typically a beam vbltage of 2, 5, 8, 10, 12, 14, 16, 18, or 20 kV negative at a Current density of 0.5, 1, or 3 nA/cm^2. Testing ie performed by starting at the lowest beam voltage arid current density and increasing these, in steps, as the test progresses.

3.3 Testing

Testing is typically perfdrmed by setting the beam conditions and Stepping thrbugh increasing beam voltages at a given current density, increasing the current density, and then again stepping through increasing beam Voltages. The sample is discharged with the plasma source before the beam valtage is changed. In this manner, conditions from -2 kV at 0.5 nA/cm^2 to -20 kV at 3 nA/cm^2 are imposed upon the sample. If the test is a survey test, each condition is maintained fbr 20 minutes br until equilibrium is attained, whichever is longer. When long term effects are under investigation, the specific conditions of interest are imposed on the sample for periods of days or weeks as appropriate.

Testing is routinely done in the dark and at ambient temperature. When photoeffects are to be deterniined, testing is repeated with the solar simulator illuminating the sample. Simulation of solar eclipse conditions call be done by testing with and withbut solar simulation for given periods of time. Eclipse testing might be performed, for example, with a -20 kV beam at 1 nA/cm^2 for 30 minute alternating periods of solar simulation and darkness.

4. CONCLUDING REMARKS

The LeRC substorm facility is in continuous, reliable operation. Characterization of spacecraft materials is in progress and some reeults have been repbcted. The facility is modified to incorporate new techniques df measurement and simulation as they are required or as they are available. Independent development of instrumentation is continuously maintained and, when Bignificant instrumentation advances are achieved, they are incorporated into the facility.

References

1. Fredricks, R. W., and Scarf, F. L. (1973) Observations of spacecraft charging effects in energetic plasma regions in Photon and Particle Interactions with Surfaces in Space, R. J. L. Grard, Editor, D. Reidel Publishihg Co., pp. 277-308.
2. DeForest, S. E., and McIlwain, C. E. (1971) Plasma clouds in the magnetosphere. J. Geophy. Res. 76(No. 16):3587-3611.
3. DeForest, S. E. (1972) Spacecraft charging at synchronous brbit. J. Geophys. Res. 77(No. 4):651-659.
4. Bartlett, R. O., DeForest, S. E., and Goldstein, R. (1975) Spacecraft Charging Control Demonstration at Geosynchronous Altitude, AIAA Paper 5-359.
5. Pike, C. P. (1975) A correlation study relating epacecraft anomalies to environmental data, in Spacecraft Charging by Magnetospheric Plasmas, Progress in Astronautics and Astronautics, Vol. 97, A. Rosen. Editor., Am. Ihst. Aeronaut. Aetrbnaut. /Mass. Inst. Tech. Press, pp. 45-60.
6. Shaw, R. R., Nanevicz, J. E., and Adamo. R. C. (1975) Observations of electrical discharges caused by differential satellite charging, in Spacecraft Charging by Magnetospheric Plasma, Progress in Astronautics and Aeronautics, Vol. 47, A. Rosen, Editof, Am. Inst. Aeronaut. Astronaut. / Mass. Inst. Tech. Press, pp. 61-76.
7. Whipple, E. C., Jr. (1975) Observation of Spacecraft Generated Electrostatic Fields in the Vicinity of the ATS-6 Satellite, AAS Paper 75-220.
8. Stevens, N. J., Lovell, R. R., and Gore, V. (1975) Spacecraft Charging Investigation far the CTS Project, NASA TM X-71795.
9. Lovell, R. R., et al. (1975) Spacecraft charging investigation: A joint research arid technology program, Pape presented at Spring Annual Meeting of the American Geophysical Union, Washington, D. C.

10. Stevens, N. J., Klinect, V. W., and Berkopec, F. D. (1976) Environmental Charging of Spacecraft Surfaces: Tests of Thermal Control Materials for Use on the Global Positioning System Flight Space Vehicle - Part 1: Specimens 1 to 5, NASA TM X-73467.

11. Stevens, N. J., Berkopec, F. D., and Blech, R. A. (1976) Environmental Charging of Spacecraft Surfaces: Tests of Thermal Control Materials for Use on the Global Positioning System Flight Space Vehicle - Part 2: Specimen 6 td 9, NASA TM X-73436.

12. Berkopec, F. D., et al. (1976) Environmental Charging Teste of Spacecraft Thermal Control Louvers, NASA TM X-73517.

13. Berkopec, F. D., and Stevens, N. J. (1976) Testing and evaluation of Solar array segments in simulated geomagnetic substorm charging conditions, Presented at the IEEE 12th Photovoltaic Specialists Conference, Baton Rouge, La.

14. Stevens, N. John, et al. (1976) Testing of typical Bpacecraft materials in a simulated substorm environment, Paper presented at the USAF/NASA Spacecraft Charging Technology Conference, Colorado Springs, Colo.

15. Purvis, C. L., Stevens, N. J., and Oglebay, J. C. (1976) Charging characteristics of materials:. Comparison of results with a simple adalytical model, Paper presented at the USAF/NASA Spacecraft Charging Technology Conference, Colorado Springs, Colo.

16. (1971) Solar Electromagnetic Radiation, NASA SP 8005.