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Contents

1. The Lewis Research Center Geomagnetic Substorm Simulation Facility

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Abstract

A simulation facility has been established at the NASA-Lewis Research Center to determine the response of typical spacecraft materials to the geomagnetic substorm environment and to evaluate instrumentation that will be used to monitor spacecraft system response to this environment. Space environment conditions simulated include the thermal-vacuum conditions of space, solar simulation, geomagnetic substorm electron fluxes and energies, and the low energy plasma environment. Measurements for spacecraft material tests include sample currents, sample surface potentials, and the cumulative number of discharges. Discharge transients are measured by means of current probes and oscilloscopes and are verified by a photomultiplier. Details of this facility and typical operating procedures are presented.

1. INTRODUCTION

Geosynchronous spacecraft have experienced anomalous electronic switching in the midnight-to-dawn region of their orbits.[1] Environmental measurements have shown that energies of transient particle fluxes are 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 been 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 has been performed in a facility specifically developed to simulate the substorm environment. This 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 0.9 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 interest is the electron environment.

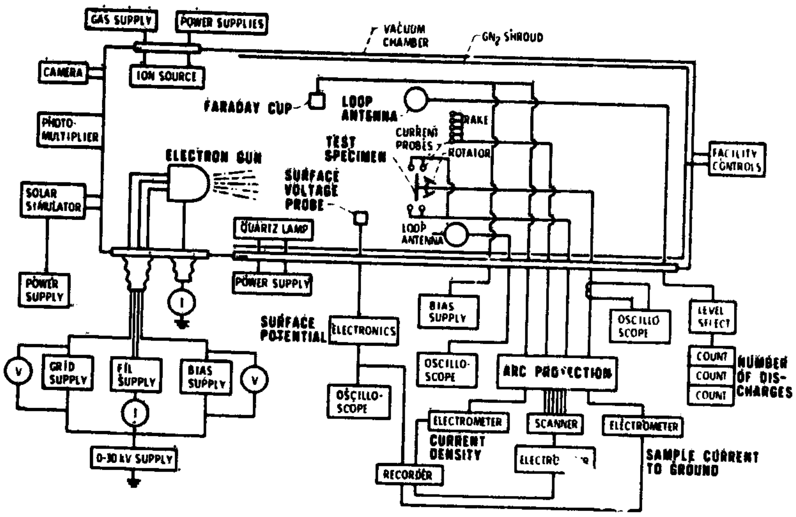

Figure 1. Schematic Diagram of the LeRC Substorm Simulation Facility

It is simulated with a monoenergetic electron beam operated at a voltage in the range from 0 to 30 kV and at a current density in the range from 0 to 5 nA/cm^2. The divergent electron beam is generated from a hot wire filament by means of a spherical segment accelerating grid kept at ground potential. The cathode and the beam-forming grids are biased negatively relative to this accelerating grid. The electron beam current density is uniform to about 30 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 to be determined. A 3/4-sun intensity xenon 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 window. The spectral distribution, with the quartz window of the chamber, is within 10 percent of that recently published[16] for solar radiation.

Low energy plasmas are simulated by means of a gaseous nitrogen electron bombardment plasma source. Nitrogen gas is admitted into a discharge chamber containing a hot wire filament cathode and 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 ionization efficiency. Plasma densities from about 10 particles per cm^3 up to 10^6 particles per cm^3 can be simulated. The plasma source is routinely used to discharge samples after testing.

2.3 Sample Accommodation

Figure 2 is a photograph of the test chamber interior. Samples to be tested are mounted on a three-position sample rotator. Up to three different samples can thus be tested during each pumpdown of the facility. Vacuum can be maintained for several weeks for survey tests of three samples. Samples up to 30 by 30 cm in 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.

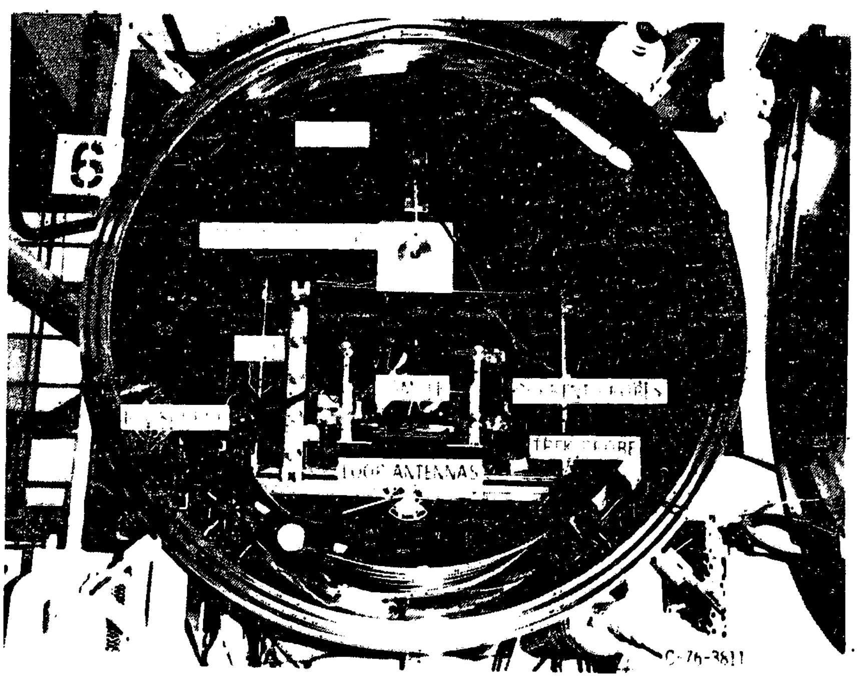

Figure 2. LeRC Substorm Simulation Facility Test Chamber Interior

2.4 Instrumentation

2.4.1 ELECTRON ENVIRONMENT MEASUREMENTS

The electron current density at the test location is measured with a Faraday cup. The Faraday cup is mounted to a 30 by 30 cm metal plate which shields the test sample. The Faraday cup-sample shield assembly is positioned in front of the sample only while the current density is being set. The entrance 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'ain metal disks, 5 cm^2 in area, that are used to monitor the current density a: 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, and rake can be seen in Figure 2.

2.4.2 SAMPLE MEASUREMENTS

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

Sample surface potential is the second basic measurement made. Surface potential is measured by sweeping an electrostatic 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 measurement and minimizes voltage gradients in the measurement location. This measurement is made in the electron beam. Since the probe and the sample are nearly the same potential, the probability of arcing between the probe and the surface under measurement is minimal. The response time of the device is 20 msec to change 10 kV; this is faster than typical charging times being measured. The probe-to-sample surface spacing is generally maintained at 2.5 mm; resolution is within 5 percent at this spacing 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 loop antennas are 15 cm in diameter and the plane of the loop intersects the plane of the sample within the sample area. The antenna-to-sample spacing is about 0.7 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 volts, for example, at the input to the discrimination circuitry then becomes the basic discharge data. When discharges occur, the sample current measuring electrometers are shorted out of the measurement circuitry and the sample current directly grounded. Inductively coupled current probes and fast oscilloscopes (100 and 250 MHz) are used to measure the arc-discharge currents. A photomultiplier tube is used to sense the visible emission portion of 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 chamber apparatus is a Polaroid camera which is used to photograph discharges. Discharge locations as well as some visual discharge characteristics are documented. Time exposures are made for varying periods, depending on the frequency of discharging.

3. TEST PROCEDURE

3.1 Initial Condition

Prior 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 plasma source. The state of the sample surface is determined from measurements by the sample surface potential probe.

3.2 Establish Electron Substorm Conditions

The electron beam is established by bringing the Faraday cup-shield assembly to its position in front of the sample shielding the sample from the electron beam. The proper electron beam conditions are then set. These conditions are typically a beam voltage 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 is performed by starting at the lowest beam voltage and current density and increasing these, in steps, as the test progresses.

3.3 Testing

Testing is typically performed by setting the beam conditions and stepping through 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 voltage 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 for 20 minutes or 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 determined, testing is repeated with the solar simulator illuminating the sample. Simulation of solar eclipse conditions can be done by testing with and without 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 results have been reported. The facility is modified to incorporate new techniques of measurement and simulation as they are required or as they are available. Independent development of instrumentation is continuously maintained and, when significant instrumentation advances are achieved, they are incorporated into the facility.

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