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Space environment - Plasma environments for generation of worst case surface electrical potential differences for spacecraft

空间环境 产生航天器表面最恶劣电位差的等离子体环境

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1 Scope

The document describes the space plasma environments that generate the worst case electrical potential differences on the surface of a spacecraft, and how a simulation program is used to estimate the worst case surface potential difference of a spacecraft.

It contains the temperature and the density of the plasma of geosynchronous orbit (GEO), polar Earth orbit (PEO) and medium Earth orbit (MEO). It does not contain the temperature and the density of the plasma of low Earth orbit (LEO).

2 Normative references

One document is cited: GB/T 32452-2015, Terminology of spacecraft space environment. For dated references only the edition corresponding to that date applies; for undated references the latest edition, including all amendments, applies.

3 Terms and definitions

The terms defined in GB/T 32452-2015 and the terms below apply. The document gives the addresses at which ISO and IEC maintain their terminological databases.

3.1 double Maxwellian distribution: the distribution functions of the electrons and of the protons of geosynchronous orbit each have two temperature components. The Maxwellian distribution function is printed as formula (1); it is not reproduced here. Its symbols are: v, particle velocity, in metres per second (m/s); m, particle mass, in kilograms (kg); k, the

Boltzmann constant, 1.380 648 52 times ten to the power of minus twenty-three joules per kelvin; n1 and n2, particle number density, in particles per cubic metre; T1 and T2, particle temperature, in kelvin (K).

3.2 differential voltage; differential potential: the potential difference between any two points of a spacecraft when differential charging occurs, in particular the potential difference between the main body of the spacecraft and an insulating surface.

3.3 inverted potential gradient: the phenomenon, caused by differential charging, in which the potential of an insulating surface or of an insulator is higher than that of the immediately adjacent conductor surface or metal; positive dielectric negative metal (PDNM).

3.4 normal potential gradient: the phenomenon, caused by differential charging, in which the potential of an insulating surface or of an insulator is lower than that of the immediately adjacent conductor surface or metal; negative dielectric positive metal (NDPM).

3.5 surface charging: the process by which charge is deposited on, or lost from, the outer surface of a spacecraft.

4 Symbols and abbreviated terms

The following symbols and abbreviated terms apply: eV, electron volt, one electron volt being 1.602 times ten to the power of minus nineteen joules; GEO, geosynchronous orbit; LEO, low Earth orbit; MEO, medium Earth orbit; PEO, polar Earth orbit; Ne, electron density; Ni, ion density; Te, electron temperature; Ti, ion temperature.

5 Principles for identifying the worst case environment

The worst case environment is defined as the space environment, measured while the spacecraft is operating in space, that produces the largest potential difference between the structure ground of the spacecraft and an external non-conducting surface or an isolated conducting surface. Such a worst case environment shall be one that has occurred in reality.

To make it valid, the density and temperature parameters of the worst case environment satisfy the following conditions: it has appeared in the literature or in a public database; the data come from valid observational measurement; and it is physically reasonable, for example it does not violate the energy density or other physical laws, and can be verified by a mature spacecraft charging simulation program, for example one of the programs given in Annex A.

6 Principles for application to spacecraft design

In the early stage of spacecraft design, spacecraft charging simulation needs to be carried out. The following points apply to that simulation.

a) Ideally, the spacecraft charging simulation is carried out first and the kinds of material to be applied to the surface of the spacecraft are decided afterwards.

b) The worst case environment parameters given in Clause 7 are used as the input of the charging simulation.

c) The charging characteristics of a material change when it is exposed to the space environment. Where practicable, the characteristics of the material after suitable ageing under the influence of the space environment are used for the simulation, following Annex B.

d) Radiation-induced conductivity changes the bulk resistivity of the material. Where practicable, the characteristics of the material after ageing by exposure to a suitable space environment are used for the simulation.

e) In the computer simulation, a suitable spacecraft geometric model, material data and environmental conditions are used. Zero potential is taken as the initial condition and the calculation is run until the potential difference is stable.

f) Annex A gives several usable simulation programs. Programs other than those given in Annex A may also be used.

7 Worst case space environment used in the simulation

7.1 Geosynchronous orbit worst case environment. Table 1 gives the double Maxwellian distribution parameters of the worst case plasma environment of geosynchronous orbit. In a single row it fixes eight quantities: two electron number densities and their two temperatures, and two ion number densities and their two temperatures, the densities in particles per cubic metre and the temperatures in electron volts. The numeric values are not reproduced here because the exponents of the density figures could not be read with certainty from the scan.

The document also recommends the use of other severe event parameters, for which see Annex C. The electron mass and the ion mass used with the table are 9.109 383 56 times ten to the power of minus thirty-one kilograms and 1.672 621 9 times ten to the power of minus twenty-seven kilograms.

7.2 Polar Earth orbit and medium Earth orbit worst case environment. Reference [3] of the bibliography gives a polar Earth orbit environment that can be used for reference.

A Annex A (informative) Spacecraft charging simulation programs

A.1 SPIS is a full three-dimensional particle-in-cell model able to calculate accurately the sheath structure and the currents at the fine features of a spacecraft surface. The surface interactions it can simulate include photoelectron emission, backscattering, secondary electron emission and conduction. The source code can be obtained free of charge from www.spis.org, and the site offers limited technical support by e-mail.

A.2 NASCAP-2k, the most recently released NASCAP program, uses a hybrid particle-in-cell method to simulate the interaction between the spacecraft surface and the plasma environment; its coverage is wide and it can build a realistic geometric model. The program brings together the capabilities of the three programs NASCAP-GEO, NASCAP-LEO and POLAR.

A.3 COULOMB-2 can be used for spacecraft charging simulation in polar Earth orbit and in geosynchronous orbit. It builds the spacecraft geometric model on the SALOME platform and visualises the results. The program calculates the plasma currents by simulation from the Maxwell equations and the particle trajectories, and solves the electrostatic equation by an integral equation method. It also contains data on the electrophysical properties of typical spacecraft materials.

A.4 MUSCAT is a full three-dimensional particle program that can be used for spacecraft in low Earth orbit, polar Earth orbit and geosynchronous orbit. Its algorithm combines the particle-in-cell method and particle tracking, and it uses parallel computing, which makes it fast. It has a graphical user interface based on JAVA-3D, used to build the three-dimensional geometric model of the spacecraft and to produce visual output. The program likewise contains a database of material properties, and it is already in commercial use.

B Annex B (normative) Simulation after ageing treatment of materials

B.1 Simulation conditions. The clause uses the multi-utility spacecraft charging analysis tool (MUSCAT) for the calculation. Figure B.1 shows the spacecraft model used. The satellite model is a cube of 3 m side; insulators are mounted on the +X face and the +Y face, the materials being a registered insulating material whose trade name the document prints only in Chinese characters, and the cover glass CMG100-AR. The number of outer boundary grids used in the calculation is 32 by 32 by 32, the grid size is 0.5 m, and the direction of light incidence is (1,0,1).

The plasma environment used in the calculation is given in Table B.1. The same environment parameters have been used in charging simulations with MUSCAT and with NASCAP-2k. On the strength of the charging simulation results, the calculation takes the SCATHA-Mullen1 double Maxwellian distribution environment as the worst case environment. The electron mass and the ion mass are 9.109 383 56 times ten to the power of minus thirty-one kilograms and 1.672 621 9 times ten to the power of minus twenty-seven kilograms.

Three materials are used in the simulation and their properties are given in Table B.2. The annex ages the registered insulating material with protons, electrons, ultraviolet light and