

ELECTRIC EFFECTS OF PLASMA PROPULSION ON SATELLITES

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ABSTRACT

This paper introduces a synthesis of plasma propulsion electric effects and presents the analyses done by the Research Department of Alcatel Space to solve these problems. The effects, directly related to the interactions of the artificial plasma created by the electric thruster can be divided in three parts. The first is the electrostatic impact of the plasma on spacecraft charging. The second kind of interactions is the influence of the plasma on solar panel performances. The last electric interaction is the creation of parasite shorting currents in the satellite structure. For each part, perturbing effects are explained, specifications and needs and also our present solutions and collaborations are described.

1. INTRODUCTION

The always increasing of satellite on orbit life and mass make the Electric Propulsion Thruster more and more attractive for station keeping on geostationary telecommunication satellites. First developed by Russian researchers, the Stationary Plasma Thrusters (SPT) technology will be commonly used on commercial satellite in Europe in a nearest future. The Alcatel Space next satellite platforms will use SPT 100 for north-south stationkeeping. However, the introduction of an electric propulsion subsystem on our telecommunication satellite represents an innovation that requires to study their potential repercussion on the other systems of the satellite.

The Research Department of Alcatel Space studies the interaction between the plasma plume of SPT 100 and spacecraft. Generally the phenomenon of surface degradation (erosion and sputtered particles re-deposition) is clearly identify as potential interaction. In the same way, the disturbance forces induced by plasma jet on spacecraft surfaces and the effects of plasma jet on telecommunication satellites are discussed in many papers. On the other hand, the electric effects of plasma created by SPT 100 or more generally by electric thrusters are less known. Nevertheless, they can lead to upsets ranging in spacecraft electronics, power loss of solar panel and disturbing sensitive electronic equipment (by the circulation of parasite currents in the structure).

In a SPT thruster, the propellant (Xenon) atoms are ionised in a discharge chamber (anode). An electrostatic field is then used to accelerate the positive ions to produce the required thrust. To prevent the spacecraft from charging, the positive ion beam must be neutralized by an equivalent negative charge. In SPT 100 this electrons source is a hollow cathode. The plasma ejected by the SPT is then neutral, cold and very dense (about 10^{17} m^{-3} 30 cm away from thruster exit). Moreover a secondary plasma is created by charge exchange collisions between fast ions (primary ions) and slow neutral atoms. This relatively dense (about 10^{12} m^{-3}) low energy plasma can expand around spacecraft. These plasmas constitute charged particles store which can create some parasite current due to the interaction between plasma and spacecraft. It is then necessary to perform detailed analysis of this possible electric interactions between plasma of SPT and spacecraft. Since 1994, Alcatel Space has worked on the interactions between plasma plume and spacecraft and greatly increased its knowledge of these phenomena. Especially a big amount of effort has been recently made in the Research Department to set up the analysis and the modelling of these effects in order to predict the impact of electrical propulsion on spacecraft.

2. SPACECRAFT CHARGING

Spacecraft charging is considered as a phenomenon associated with the interactions between plasma and spacecraft surfaces. Charging effects can produce potential differences and high electrical field between spacecraft surfaces or between spacecraft surfaces and spacecraft ground. Above breakdown threshold, an electrostatic discharge (ESD) can occur. The transient phenomenon generated by this discharge may couple with spacecraft electronics (ElectroMagnetic Compatibility) and cause upsets ranging from logic switching to complete system failure. Discharges can also lead to degradation of exterior surface coatings and induce contamination of surfaces.

The charge and discharge phenomena due to the natural plasma in geostationary environment are studied for a long time. Methods and design rules have been set out to prevent from spacecraft charging and ESD occurrences in this environment¹. But, the charged particles flow ejected by the electric thruster creates an artificial plasma which modifies the natural electrical

environment of the spacecraft. The software ESCAPE² (ElectroStatic Charging in Artificial Plasma Environment) developed in collaboration with the RIAME (Research Institute of Applied Mechanics and Electrodynamics in Moscow) simulates the electrostatic charging of a spacecraft with electric propulsion on board in geo-stationary environment. This software calculates the modification of spacecraft surfaces charges and potentials due to the plasma of the electrical propulsion. Its main inputs, in addition to the geometrical description of spacecraft, the physical properties of surface materials and the parameters describing the geo-stationary environment, are the location of the thruster, the direction of the plume and the distribution in angle of the particles (ions and electrons) velocity and current density. The outputs are the time dependence of potentials and electrical fields for surfaces cells, the time dependence of the current density of each type of particle (current balance) on surface cells, the 3-D visualisation with color indication of the potentials and electric fields on surfaces (figure 1) and visualisation of ions and electrons trajectories coming from the electric thruster (figure 2).

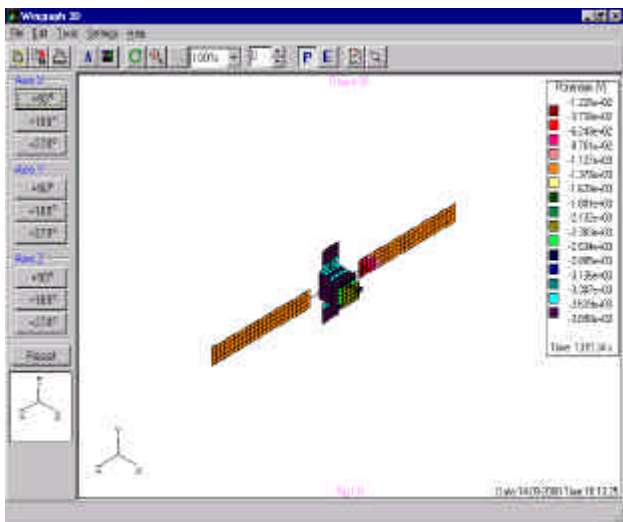


Figure 1 : 3D visualisation of surface potentials

The study of the capabilities of this new software is now in progress at Alcatel.

Escape will be used to predict the surface potentials when spacecraft is submitted to both geostationary environment (geomagnetic substorms) and plasma from the electric thruster.

This prediction is necessary to verify that the surface potentials meet the specifications (classical tolerable levels according to the NASA guidelines, -1000V and +500V).

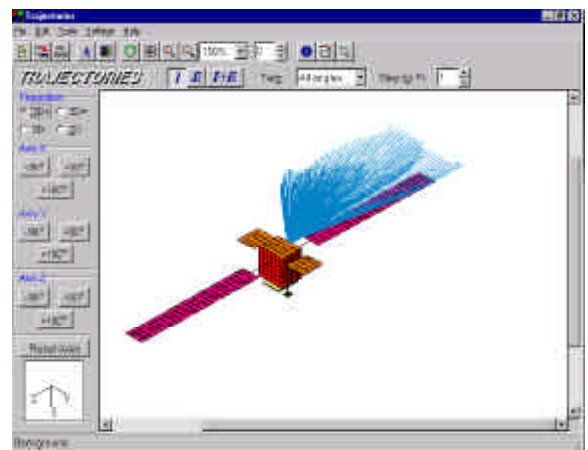


Figure 2 : particles trajectories from SPT thruster

3. SOLAR PANEL POWER LOSS

When the solar panel is in contact with a dense and cold plasma, it can, because of its active tension, collect a parasitic current from the plasma which passes through the solar cells and creates a power loss. This power loss is mainly function of the plasma characteristics (density and energy), solar array active voltage and spacecraft structure characteristics. The collection of parasitic current can arise from interaction between the solar array and the ambient space plasma (in Low Earth Orbit) or interaction between the solar array and the low energy dense plasma emitted from electric thruster³.

Examine the voltage-current characteristics of a conductive element immersed in a plasma. The active voltage is externally applied and the current collected from the plasma is measured. This is the principle of a Langmuir probe. The typical curve obtained is given figure 3.

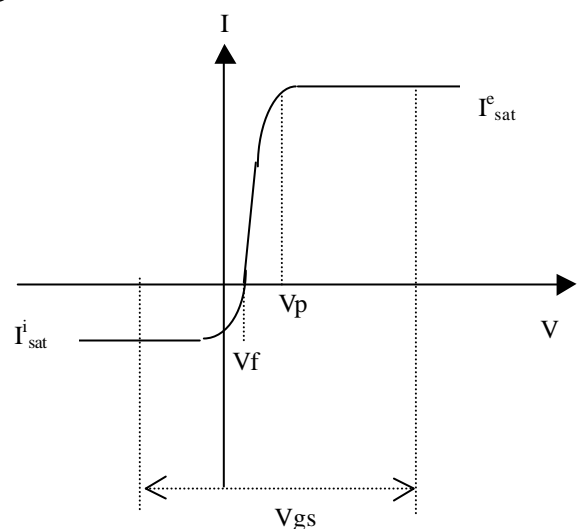


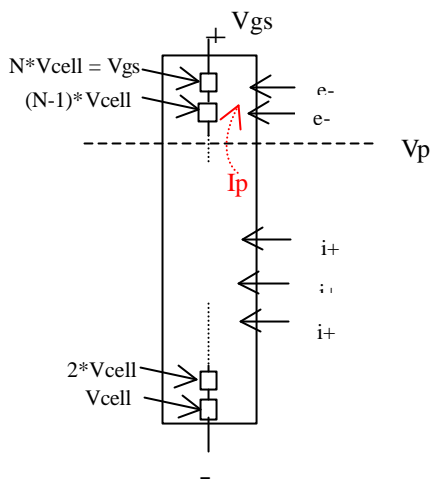
Figure 3

If the probe is not polarised, the potential V_f at which the probe floats corresponds to the equilibrium state where the sum of current on the probe is zero.

At the plasma potential V_p , the probe doesn't disturb the particles trajectories. The charged particles migrate to the probe because of their thermal velocities. Since electrons move much faster than ions because of their small mass, the probe collects predominantly electron current. If the probe voltage is superior to V_p , the ions are repelled and the probe collects mainly electrons (I_{sat}^e). On the contrary, at large negative value ($V \ll V_p$) nearly all of the electrons are repelled, and we have only an ions current (I_{sat}^i).

Between V_f and V_p (transition region), the electrons begin to be repelled and the ions accelerated. If the electrons distribution is Maxwellian, the shape of the curve here is exponential: $J_e = J_{e0} \exp[-e(V - V_p)/kT_e]$. So if the electron energy, T_e , is low the current increases rapidly between V_f and V_p . In other words, this transition region is very small.

A spacecraft in space environment or in any other plasma acts like a Langmuir Probe. Each surface of the spacecraft will assume the floating potential (V_f), function in this case of the surface material characteristics. More particularly, the passive conductive structure of spacecraft will adjust itself to the floating potential. But, a solar array is an active system. By the working of solar cells, the solar array develops active voltage. If we consider that the solar array is constituted of only one string of the solar array, the voltage is distributed along the string as shown on the figure 4. In a cold and dense plasma the active voltage V_{gs} is higher than the interval $[V_f; V_p]$ (see figure 3). The floating condition for the solar array requires that the zero potential point of the array adjusts itself so that no net current is collected; that is, the collection of ions equals the collection of electrons. In balancing currents, the spacecraft conducting-area must be taken into account. In these conditions, in a dense and cold plasma some cells will collect a high electrons current (I_{sat}^e) whereas the other part of cells will collect ions⁴⁵:



The electrons collected by the cells generate a parasitic current in these cells. The overall effect on the solar array of parasitic current is to change the effective operating point of the solar array: The current at each solar cell is the sum of normal load current and parasitic current. So as the figure 4 of solar cell I-V curve shows it⁶, when the current increases the potential decreases and so degrades useful array power output.

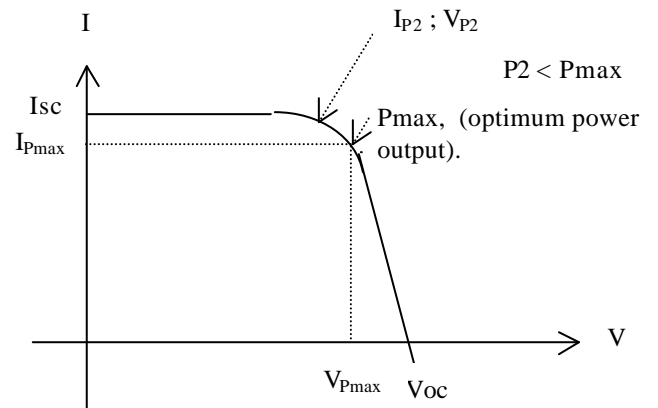


Figure 4 : Solar cell I-V curve

Extending the operating voltage of solar arrays to higher levels ($> 100V$) requires to consider the power loss due to the interaction with dense and cold plasma. Indeed, the parasitic current collected by the solar cells from the plasma may substantially impact the capability of the array to deliver the required power. In geostationary environment (hot and not very dense plasma) the parasitic current is a very small fraction of the array current and is therefore not observed. But this parasitic current may result from the interaction of spacecraft-generated plasma by electric thruster and high-voltage solar array. The plasma can be either the plasma jet ejected by the thruster. In this case, in our spacecraft configuration, the inboard sections of the solar array will be the most affected. Or it can be the Charge-EXchange plasma (back flow) generated by the electric thruster. This plasma is less dense than the primary plasma jet, but it can be sufficient to generate power loss on some section of solar array. For example if we consider only the first inboard string of our GS (at about 2.5 m of the thruster), the density of plasma at this place is about $1.5 \cdot 10^{12} \text{ m}^{-3}$ and the temperature is about 2 eV. In this case with SPENVIS/SOLARC, we can estimate the parasitic current. In the conditions described above, the order of magnitude of the parasitic current through one string is about a few mA, that is relatively negligible towards normal load current (about 1-2 A). But it is necessary to estimate more precisely this current because a lot of parameters impact the results: The model of current collection (secondary emission, photoemission), the geostationary environment, the sheath effect on the connectors. Of course, parasitic current can be calculated if the

elements of SC structure through different zones, a shorting current will be generated in these elements (case 1 of the figure 7 below).

In the same way the secondary plasma produced by the back flow can generate shorting current in the conductive structure of the spacecraft when they are in contact with it (case 2 of the figure 7).

Another case can occur : One part of spacecraft structure, the Solar Array (SA) for example, is in contact with the plasma jet of the thruster while another part is in contact with secondary plasma. In this case, a shorting current will circulate between the solar array and the spacecraft body (case 3 of the figure 7). This case could be critical because these currents create a large current loop (with size equals approximately to the size of the Spacecraft plus the solar array). This current loop oscillates in correlation with the pulses of the EP discharge current and therefore creates magnetic oscillations and consequently potential electromagnetic interference. Moreover, these oscillations increase after some hours of the thruster operating.

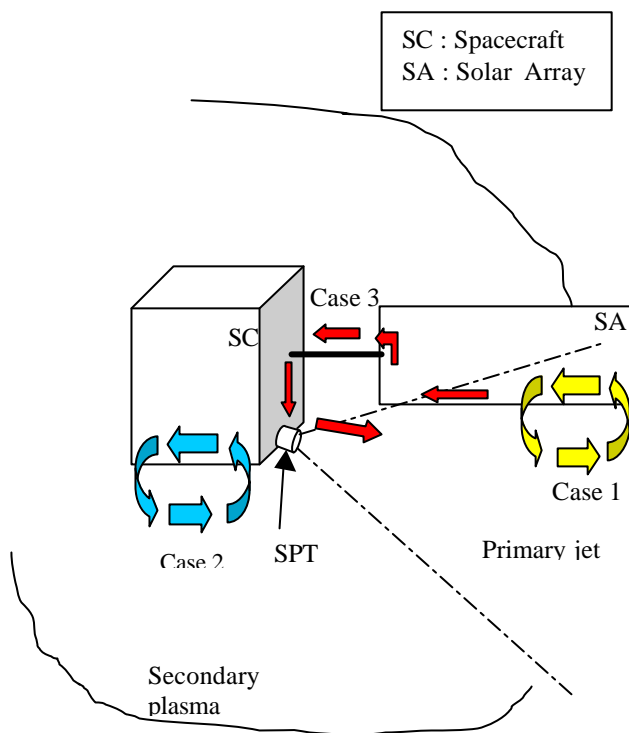


Figure 7

This last case is probably the most critical because the plasma ejected by the thruster is cold (2 eV) and very dense (about 10^{13} m^{-3} at 4m from the thruster). This plasma can provide a high current density (about 0.4 A/m^2 at 4m from the thruster).

A collaboration with the TsNIIMASH (Moscow) has been built up in order to perform an analytical study on shorting currents generated by the interaction between SPT 100 and spacecraft. In a first phase of the study, an order of magnitude of the shorting currents intensity will be determined to have an estimation of the criticality of this phenomenon. The results will be compared with the specification of common mode emission on structure (Ampere peak versus frequency).

5. CONCLUSION

Fruits of a continuous effort, Alcatel Space has drastically increased its knowledge concerning the electric effects of plasma propulsion on spacecraft. Based on theoretical studies, numerical developments and international collaborations, we can say that no major electric risks are associated with the use of plasma propulsion. The future work of the Alcatel Space Research Department will be to study all these electric effects as a whole. Indeed, these effects are not independent of each other.

REFERENCES

- [1] : "Règles de conception et Méthodes de Test Système"
G. Safeno (Alcatel Space Industries, France)
Cours de Technologie Spatiale (CNES), Environnement Spatial, Pévention des Risques liés aux Phénomènes de Charge, juin 1996.
- [2] : "ESCAPE : Software Modeling Package for Forecasting the Electrostatic Charging of Satellite with Electric Propulsion in the Ionosphere of Earth"
A.P. Plokhikh, V.G. Malko, V.A. Semenov (Riame, Russia)
C. Berthou, S. Brosse (Alcatel Space Industries, France)
3rd International Conference on Spacecraft Propulsion.
- [3] : "Effect of Parasitic Plasma Currents on Solar-Array Power output".
Stanley Domitz and Joseph C. Kolecki, NASA Lewis Research Center.
- [4] : Environmental Interactions of Solar Generators in Space"
K. Bogus, ESA/ESTEC
Space Environment Technology, CNES, April 1986.
- [5] : "Charge des Matériaux et Systèmes en Environnement Spatial"
Léon Levy , ONERA/DESP

Cours de Technologie Spatiale (CNES), Environnement Spatial, Pévention des Risques liés aux Phénomènes de Charge, juin 1996.

[6] : “Solar Cell Array Design Handbook” The Principles and Technology of Photovoltaic Energy Conversion”
H.S. Rauschenbach, TRW Defense and Space Systems Group.