ION BEAM SIMULATION IN A SPACECRAFT ENVIRONMENT

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Abstract

We suggest to use the calculation methods in the three–dimension area surrounding spacecraft for the analysis of motion of charged particles which are emitted by electric propulsion engines. Our method is also used for wide area of physical problems.

1. The problem

1.1. Possibilities of the method suggested

The charge particles motion trajectory calculation in superposition of electric and magnetic fields in the vicinity of three dimensional complex surface object cannot be done by analytical methods. Generally, the usage of computer calculation models of the motion trajectories leads to the large memory volume and spending time. Our method gives us the possibility to solve the wide spectrum of physical problems by using the middle power PC for any configuration of the complex object in which environment the particle motion is investigated.

There are the problems:

– The research of the trajectories of the particles emitted by the electric propulsion engines of the object in the electric and magnetic fields of arbitrary configurations;

– The determination of angle and energetic distortion of spectrometers;

– The determination of own external atmosphere (OEA) in the vicinity of three dimensional object for given values of gas desorption coefficients and from various elements;

– The terminator motion along the complex object surface during its orientation variation in respect to the light source;

– The investigation of cosmic apparatus electrization at certain external conditions.

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1.2. Physical approximation

For modelling of the charged particles trajectories the approximation of its independent motion is used, i.e. the collective phenomena are absent. The initial data are the electrical potentials (or its gradients) and magnetic induction vector value in the vicinity of the object. The particle initial velocities and masses in the object coordinate system are set. Such approximation allows us to search for all possible particles motion trajectories independently from its appearance location. This allows us to ignore the "stream–particle" interaction detail learning.

1.3. The realization

The mathematical model was created in INP MSU for spacecraft electrization analysis in plasma environment [1]. These trajectory calculation method possibilities are founded on the discrete description of the object and its surrounding space.

The trajectory of any particle is approximated by part–continued way in each cell. At reaching the calculated space border the observation of particular particle is over and all the calculation is started for the next particle.

The calculation speed at the PC/386 is 1000 trajectories per second for the version that we have.

2. The method for modelling of the particle motion

2.1. The discretization of three dimensional object

The geometric complex object model is considered as a set of some elementary surfaces: the plane, the tore, the elliptical cylinder, the ellipsoid, the elliptical cone and the elliptical diaphragm with hole.

The elementary surfaces are got by parametrical variable quantity at the own local coordinate system. Transformations of translation and Euler angle rotation are used for the transition to the model connected coordinate system.

All elementary surfaces are separated into rectangles in the parametric space. These rectangles are divided by diagonals into two triangles. The gravity centre coordinates as a medians crossing point is determined in parametric coordinate system for every triangles. The model geometric data base in its coordinates system contains the created in such a way parametric triangle gravity center coordinates and contains the every triangle square, the gravity centre single normal direction, the division quantity at every parametric variable quantity [2].

2.2. The calculation space discretization

The three dimension calculating space is performed as a set of regular cells. The configuration of planes limited cells may be as you wish (cubes, tetrahedrons and etc). The calculation space is divided into two subareas for trajectory calculations. The first subarea cells contain the object surface elements and are forbidden for particle motion.

The second subarea cells are free from the object and the particle motion is allowed there. The particle motion modelling in the space is done by the calculation of its coordinates step by step in every cell. When the moving particle passes from the second subarea to the first subarea one can consider that the particle is on the object surface.

For the trajectory calculations the relation between the space cell size and the discretization degree should satisfy the requirement for mathematical surface to have "no holes". This means that the continuous physical surface must be continuous in mathematical sense at the modelling, i.e. impenetrable for the particles [3].

2.3. The electrical and magnetic field description

The initial data for the potentials and its gradients are settled at the cell tops. In the case of spacecraft electrization in the rarefied high temperature plasma (the Debye radius is about several hundred meters) the electric potentials of about 10 kV [4] are formed on its surface. In this case, the external electric fields are too small in comparison with own apparatus field and such a way may not be considered in the calculations. The Debye radius reduces to the units of centimeters for the more dense plasma.

The magnetic field in the vicinity of the object is determined by the sum of field of installed board devices and the external magnetic fields.

The distribution of the potential in the vicinity of the charged object is obtained by solving the three dimension Laplace equations [5].

3. Examples of calculations

3.1. The charged particle motion in the electric field of spacecraft

For the detailed analysis of electric propulsion engines put the charged particles starting points in the plasma injecting direction. The trajectories of positive charged

ions in the vicinity of differentially charged spacecraft are shown on fig. 1. It is clear that the formation of charged particles streams is possible.

Generally, the positive ions have very complex trajectories in the vicinity of differentially charged spacecraft, as shown on the fig. 2.

3.2. The motion in electric and magnetic field superposition

The positive ion motion trajectories in the vicinity of charged object at the external constant fields are shown on fig. 3. The trajectory projections on two perpendicular to each other planes at magnetic induction vector value H = { 0, 0, H } are shown on the left, and on the right – for value 0.1H. It is clear from the figure that the magnetic field can modify the charged particle trajectories significantly.

3.3. Other applications of the method

The same program complex is used for the neutral particles motion analysis and for the terminator board on the surface of the complex form object. In this case, the particle acceleration in every space cell need not to be calculated. All trajectories are lines.

The particles motion time reversibility allows us to use the reversed trajectory method for the problem of determining the terminator board. For this the one particle flight to the light source direction from every discrete object surface element occurs. If the particle reaches the external calculation space boundary the given element is illuminated. The example of such calculation is shown on fig 4. The possibilities of method for analysis of distortion of on–board spectrometric devices data are shown on fig. 5. It is clear that the different energy particles are gathered from different parts of calculation space, including the emitted from the spacecraft surface particles.

Knowing the coefficients of gas desorption from every cell on the three dimensional object surface, setting angular distribution of the emitted particles and introducing the reflection and absorption parameters of particles, one can solve the problem of own external atmosphere (OEA) concentration determination in the vicinity of the object. If the trajectories are in the space cells you have to summarize the quantity of every type of particles. The equal–concentration lines in OEA in the vicinity of the object can be separated visually. One example for the different coefficients of gas desorption from the surface elements is shown on fig. 6.

Conclusion

The wide opportunities of the method which allow us to do mathematical modelling of the charge particles motion near the charged object of complex geometry in electrical and magnetic field superposition on middle power PC are shown in our work.

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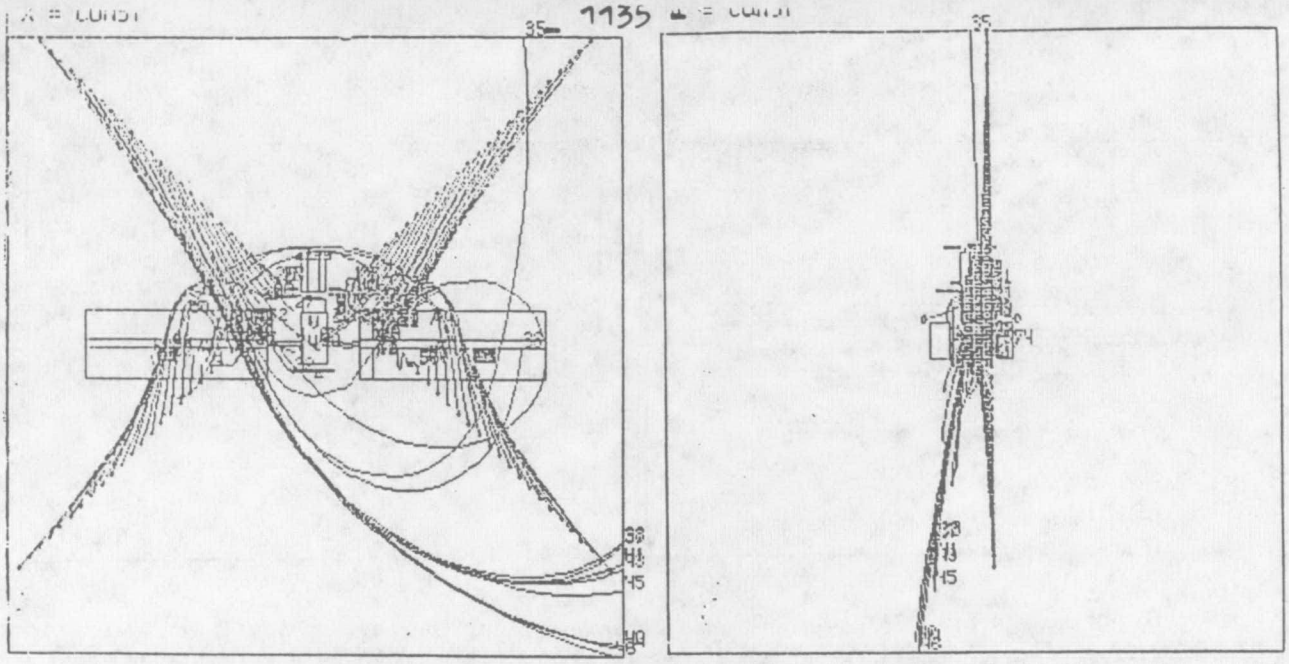


Fig.1. The projections on the two perpendicular to each other planes of positive ions trajectories which emitted from electric propultion engines installed on the board of the different charged spacecraft.

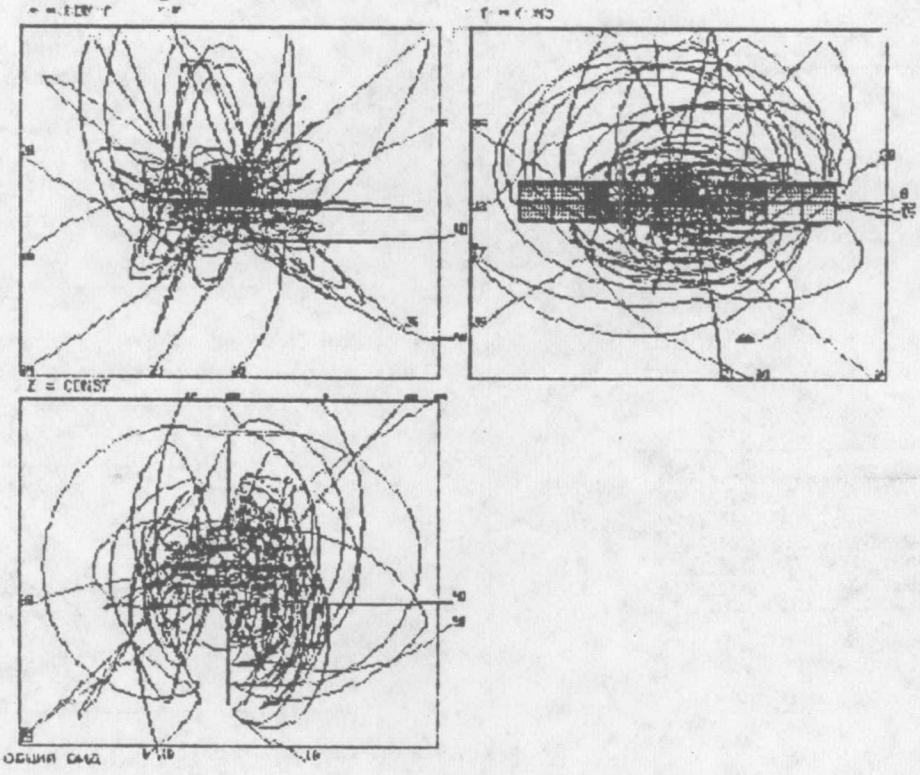


Fig. 2. The example of very complex trajectory of positive ions in the vicinity of differentially charged spacecraft.

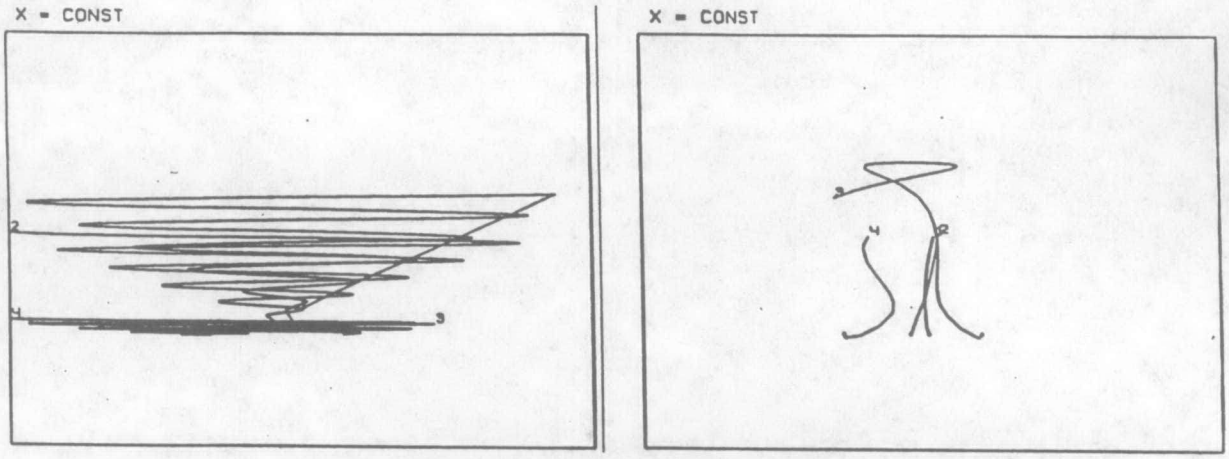
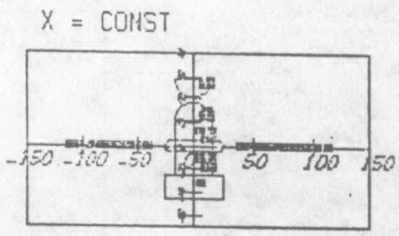


Fig. 3. The projections of positive ions trajectories for the case of the spherical electric and the constant magnetic field superposition. On the left figure the value of magnetic field is factor of ten that on the right.



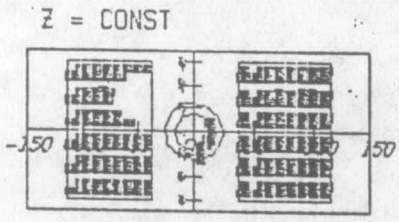


Fig. 4. The spacecraft model projections and the marks which are illuminated.

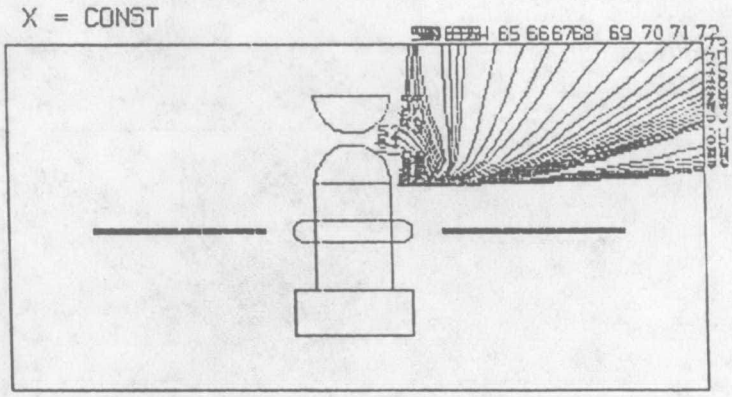


Fig. 5. The bending of charged particles trajectories of different energies gives rise to angle distortions of spectrometrical devices.

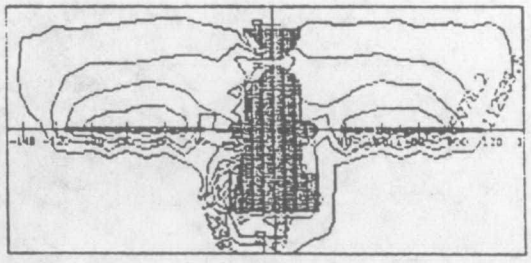


Fig. 6. The curves of equial concentrations of own external atmosphere in the case of different gas-emitted coefficients from the different spacecraft surface elements.