THE MAGNETIC FIELD EFFECT ON PHOTOELECTRON CURRENT FROM A POSITIVELY CHARGED SPACECRAFT

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ABSTRACT

The relations to obtain the dependence between electron density of ambient plasma and spacecraft electric potential measured by double probe technique are based on current balance to and from spacecraft body [1,2,3]. As a rule only electrostatic effects are considered. In general such an approximation gives rather good results [4,5,6,7].

Meanwhile there are some cases where the role of magnetic field in retarding of photoelectron outflow can not be neglected. This effect can cause an overestimation of electron density for given conditions. It becomes really important in respect to thermal plasma measurements (i.e. for particle energies of the order of S/C potential) where the precise cutoff of ion spectrum should be determined.

The work presents some model calculations for photoelectron current outflow efficiency and search of parameters where this effect becomes substantial.

MODEL DESCRIPTION

As an object of the model a Sun-oriented spacecraft approximated by disk with radius R_{max} is considered (*Fig.1*). The coordinate frame is selected so as Y-axis is directed to the Sun, X- and Z-axis are in plane Y*=0*.

Magnetic field **B** is in YZ-plane and inclined at angle *b* to the S/C-surface, so $B_x=0$.

We consider here only the hemisphere Y*>0* and the outflow from the sunlit surface solely is examined.

Electric field of the charged spacecraft is directed along Y-axis and limited by two Debye lengths r_D in XZ-plane, so for $y=0$, at the disk vicinity $[R_{max}+2r_D]$, the S/C potential $f=f_0$, and out of that region $f=0$. We also assume that S/C electric potential becomes negligible 2 r_D from the surface along the Y-axis.

Ph-electrons leave the surface with initial velocity $\mathbf{v_0}$ at the arbitrary angle *a* to the surface plane and at the arbitrary angle *q* between X-axis and velocity projection to the spacecraft surface.

The criteria for a *ph*-electron escape from the satellite were set as follows:

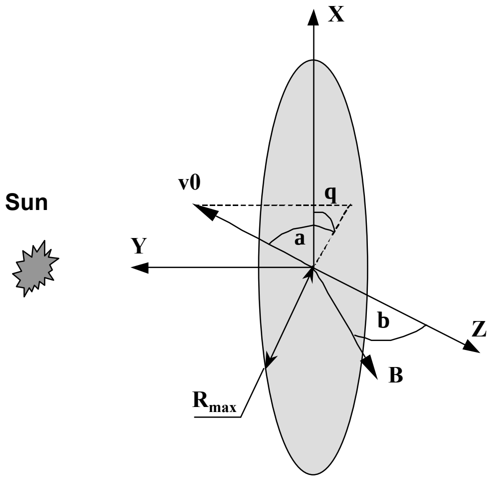


Fig. 1 *Approximation of the Sun-oriented spacecraft, used in model calculations*

$r_{XZ} > 2R_{larm}+R_{max}$ – in the XZ-plane,
$r_Y > 2R_{larm}+2r_D$ – along the Y-axis, (1)

i.e. it is supposed that *ph*-electron escape from the satellite if the electric field produced by charged pacecraft can be disregarded along a Larmor orbit of the given electron.

The density and temperature of ambient plasma as well as the value of S/C electric potential and magnetic field magnitude and inclination to the satellite surface were used as external parameters for the model. Varying them the dependencies for effective photoelectron current were studied.

EQUATIONS

The force determining the particle motion is:

$$\frac{d^2\mathbf{r}}{dt^2} = \frac{q}{m}\left(-\mathbf{grad}f + \frac{1}{c}\cdot[\mathbf{v}\times\mathbf{B}]\right) \tag{2}$$

where:

$$f = f_0 \cdot \exp\left\{-\frac{y}{r_D}\right\} \tag{3}$$

- the electric potential distribution along Y-axis,

$$r_D = \sqrt{\frac{kT_e}{4p \cdot N_e q^2}}$$ - Debye length

N_e, T_e - density and temperature of the ambient electrons.

Writing down (2) in components, the electron motion can be described by the following system of the differential equations:

$$\begin{cases} \dfrac{d\mathrm{x}}{dt} = \mathrm{v}_x \\ \dfrac{d\mathrm{y}}{dt} = \mathrm{v}_\mathrm{y} \\ \dfrac{d\mathrm{z}}{dt} = \mathrm{v}_\mathrm{z} \\ \dfrac{d^2\mathrm{x}}{dt^2} = -\dfrac{e}{mc}\left(\mathrm{v}_\mathrm{y}\cdot \mathrm{B}_z - \mathrm{v}_\mathrm{z}\cdot\mathrm{B}_y\right) \\ \dfrac{d^2\mathrm{y}}{dt^2} = \dfrac{e}{mc}\cdot\mathrm{v}_x\cdot\mathrm{B}_z - \dfrac{e}{m}\cdot\dfrac{1}{r_D}f_0\cdot\exp\left\{-\dfrac{\mathrm{y}}{r_D}\right\} \\ \dfrac{d^2\mathrm{z}}{dt^2} = -\dfrac{e}{mc}\cdot\mathrm{v}_x\cdot\mathrm{B}_y \end{cases} \tag{4}$$

where $\mathrm{B}_\mathrm{y} = \mathrm{B}\cdot\sin b$, $\mathrm{B}_\mathrm{z} = \mathrm{B}\cdot\cos b$, e, m – electron charge and mass, with initial conditions vector:

$$\begin{pmatrix} \mathrm{x0} \\ \mathrm{y0} \\ \mathrm{z0} \\ \mathrm{v0}_x \\ \mathrm{v0}_y \\ \mathrm{v0}_z \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \mathrm{v0}\cdot\cos a\cdot\cos q \\ \mathrm{v0}\cdot\sin a \\ \mathrm{v0}\cdot\cos a\cdot\sin q \end{pmatrix} \tag{5}$$

The system (4) was solved numerically. We present the results obtained and discus them below.

CASE STUDY

For further analysis let us set the characteristic size of the spacecraft $R_{max}=200$ cm.

Assuming the ambient plasma parameters as $N_e=10\ cm^{-3}$, $T_e=1\ eV$, spacecraft potential $f_0=2V$, which are very typical for middle altitudes in the Earth magnetosphere we can investigate the behavior of a photoelectron without and with magnetic field.

For the case study ph-electrons with energy *Eph* of *3 eV* leaving the s/c surface in X-direction under angles $a=10°, 45°, 80°$ are considered as the "test particles".

Without magnetic field the all three *ph*-electrons will escape the satellite due to the energy is enough to surmount the s/c potential barrier (*Fig.2*).

The trajectories of those ph-electrons become completely different when magnetic field is introduced to the calculations. As an example the case $B=5000\ nT$, β=45°, is shown on *Fig.3a,b*. One can see that ph-electrons will return to the spacecraft surface due to magnetic field effect despite their energy is higher then the S/C potential.

Another case study illustrates the ph-electron behavior for the different inclination b of magnetic field to the s/c surface (*Fig.4a,b*). The test ph-electron leaves the s/c surface at the angle of 45° in X-direction.

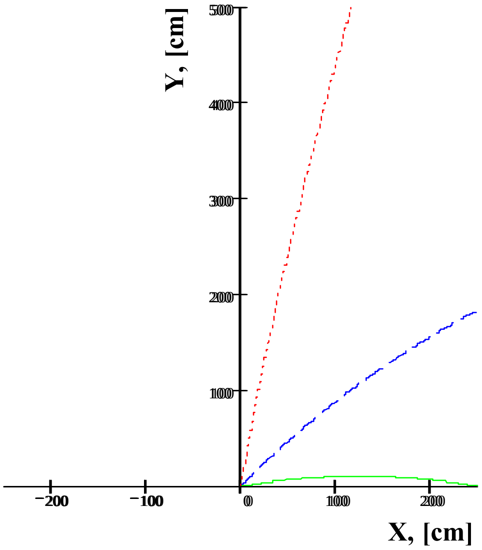
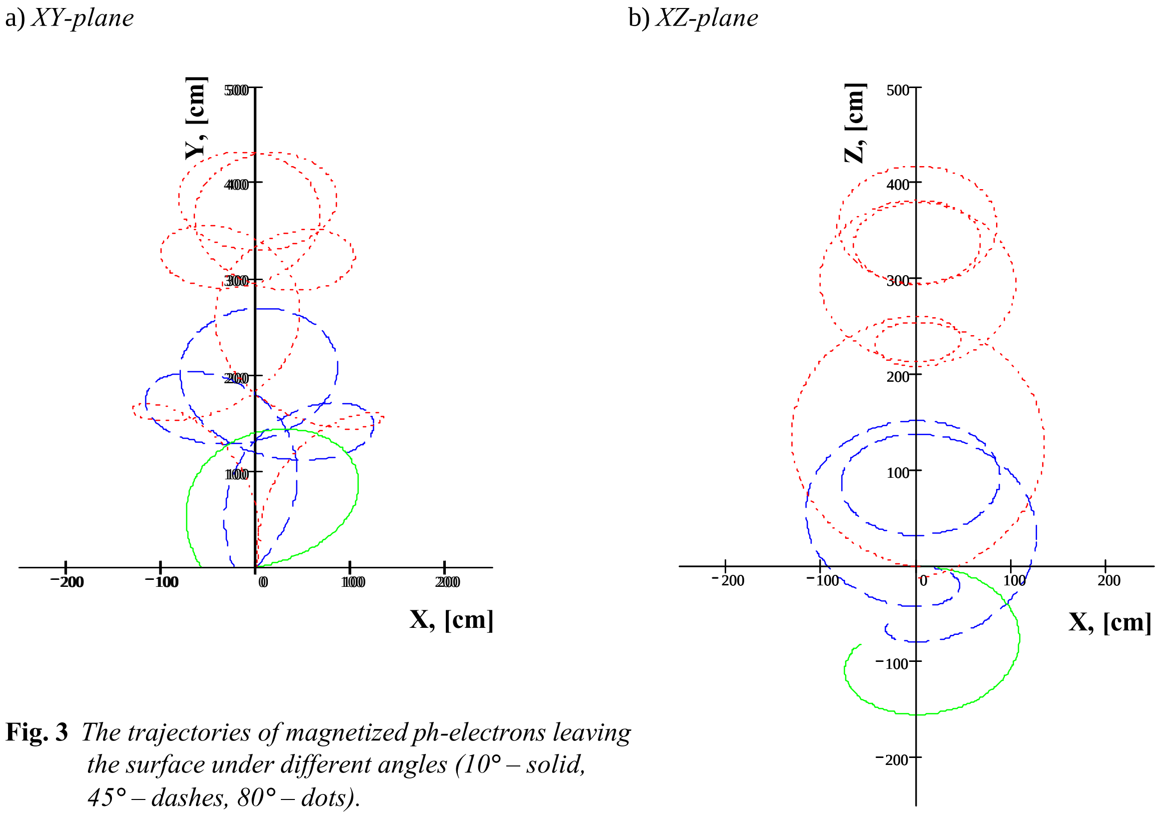
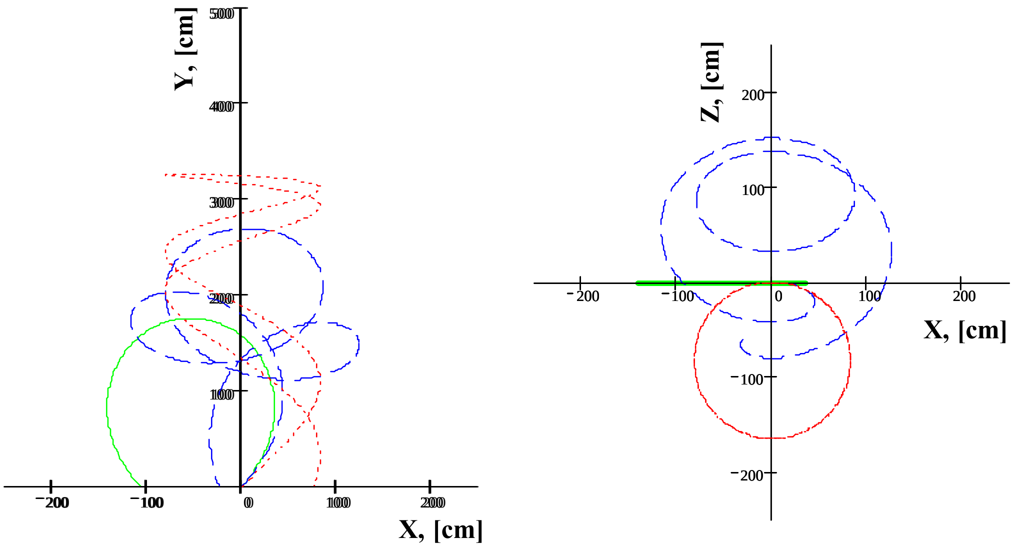


Fig. 2 *Ph-electron trajectories leaving the surface under different angles (10° – solid, 45° – dashes, 80° – dots) without magnetic field*


a) *XY-plane*

b) *XZ-plane*

Fig. 3 *The trajectories of magnetized ph-electrons leaving the surface under different angles (10° – solid, 45° – dashes, 80° – dots).*



a) *XY-plane* b) *XZ-plane*

Fig. 4 *The trajectories of ph-electrons for different inclination* b *(0° – solid, 45° – dashes, 90° – dots) of magnetic field to the s/c surface.*

As it follows, magnetic field governs the *ph*-electron motion in two ways: the component parallel to the surface forces them to return to the surface while the perpendicular component holds *ph*-electrons longer within the region of the retarding electric field of the Langmuir sheath of positively charged S/C.

RESULTS AND DISCUSSION

Finding the magnetic field effect essential for individual ph-electrons lets turn to the estimation of magnetic field influence on the photoelectron outflow current efficiency.

For a given direction determined by the angles *a*, *q* and given parameters **B**, N_e, T_e, f_0, the velocity v_{out} allowing photoelectrons to escape the satellite can be obtained.

Assuming the velocity distribution function for photoelectrons as Maxwellian with $T_{ph} = 1.5\ eV$, the fraction $n_{out}(a,q) = N_{out}/N_{ph0}$ of photoelectrons really escaping the spacecraft surface in given direction can be found as:

$$n_{out}(a,q) = \int_{v_{out}(a,q)}^{\infty} f(v)\,dv \qquad (6)$$

Varying the angles *a* and *q* over all the hemisphere the total fraction of escaping photoelectrons can be obtained (the uniform angular distribution of *ph*-electrons is supposed). Assuming the photoelectron production rate normalized as $J_{ph0} = 1$, the dimensionless real photoelectron current density can be calculated as:

$$\frac{J_{ph}}{J_{ph0}} = \int_{0}^{\text{ð}} \left[\int_{0}^{2p} n_{out}(a,q)\,d\text{è} \right] d\text{á} \qquad (7)$$

The photoelectron current density dependencies on various parameters are presented on *Fig.5; 6a,b*.

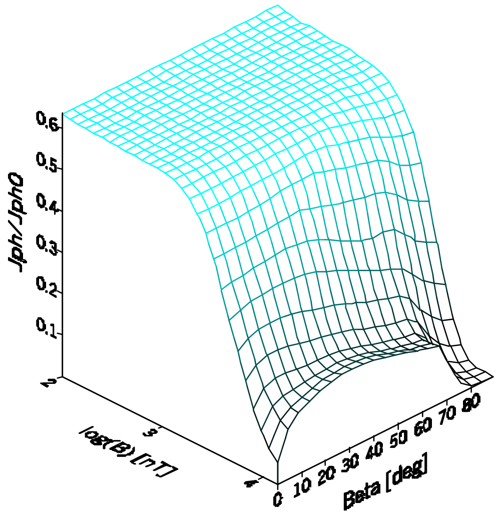
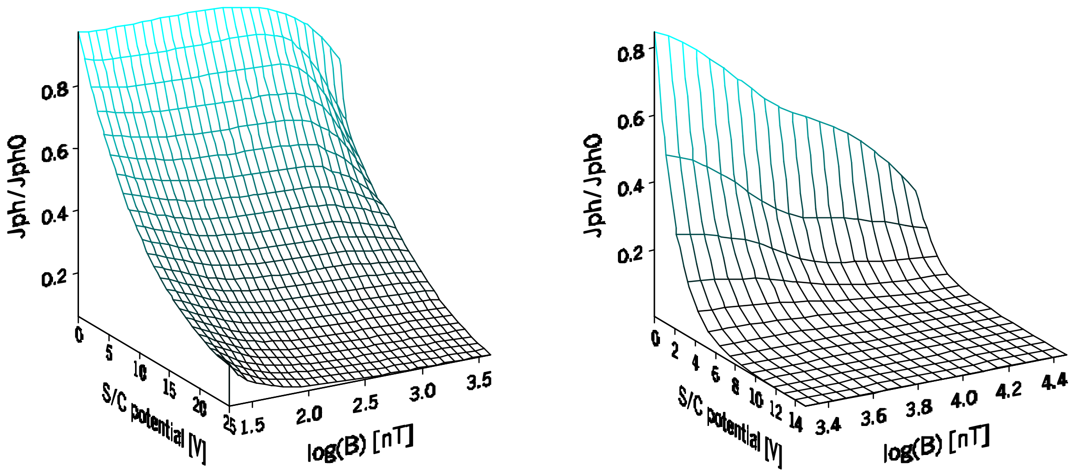


Fig. 5 J_{ph}/J_{ph0} *vs magnetic field magnitude and inclination to the s/c surface.* $N_e = 10\ cm^{-3}$, $T_e = 5\ eV$, $f_0 = 2\ V$.



a) *B=200-4000 nT,* N_e*=10* cm^{-3}*,* T_e*=5 eV, b =45°* b) *B=2000-30000 nT,* N_e *=100* cm^{-3}*,* T_e *=1 eV, b =45°*

Fig. 6 J_{ph}/J_{ph0} *vs magnetic field magnitude and s/c electric potential for ambient conditions simulating a) high and b) middle altitudes.*

The last figure shows the photoelectron current density dependence on the S/C c size R_{max} (*Fig.7*).

Really the ph-electron spectrum is much wider them Maxwellian one in its low-energy part what will cause the demonstrated effect even more bright.

Each of the four profiles presented corresponds to different set of ambient parameters. The model parameters selected are typical for the various regions of the Earth magnetosphere and can be met along the same high inclination orbit with high eccentricity (for example, the *INTERBALL-2* satellite orbit with ~20000 km apogee, 1000 km perigee, 62.8° inclination). The Profile 1 – inner plasmasphere, Profile 2 – plasmapause, Profile 3 – polar cap in outer plasmasphere, Profile 4 – closely to magnetopause.

CONCLUSIONS

1. The magnetic field effect is essential for current balance of the positively charged spacecraft in range 0÷+6 V and can change the effective photoelectron current in several times.

2. Smaller spacecraft will be charged more positively under the same ambient conditions. In particular, unbiased isolated probe will have a higher floating positive potential then s/c body.

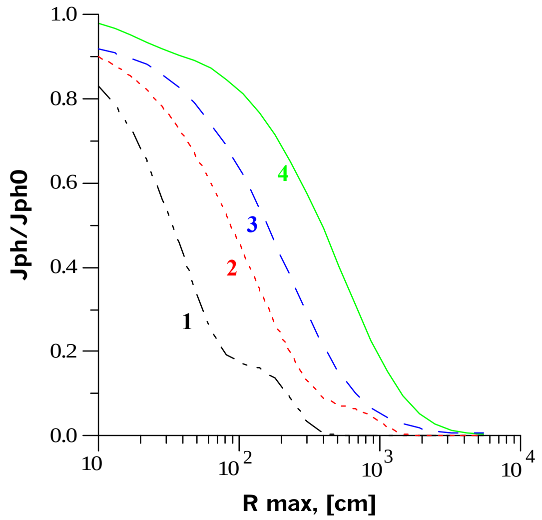


Fig. 7 J_{ph}/J_{ph0} *vs characteristic size of the spacecraft.*

1.- *B=20000 nT,* N_e *=1000* cm^{-3}*,* T_e *=1 eV,* f_0 *=1 V;*
2.- *B=5000 nT,* N_e *=100* cm^{-3}*,* T_e *=1 eV,* f_0 *=2 V;*
3.- *B=1000 nT,* N_e *=5* cm^{-3}*,* T_e *=1 eV,* f_0 *=5 V;*
4.- *B=200 nT,* N_e *=1* cm^{-3}*,* T_e *=5 eV,* f_0 *=10 V;*

3. Photo-emission material properties obtained in the ground testing should be extrapolated to space conditions taking into account the great difference in magnetic field value for the orbital conditions and for the Earth surface.

4. Magnetic field increase towards lower altitudes along the satellite orbits, and the respective dumping of photoelectron outflow, could cause apparent decrease of the photoelectron production rate along with the impact of atmospheric oxygen on the emitting surfaces.

5. The Pedersen-Esqoubet curve (S/C-potential vs ambient electron density) depends on the magnetic field strength and the size of S/C sunlit surfaces and thus can differ for different satellites.

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