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Determining The Function Of Splitting The Charged Particles Of The Strongly Ionized Air Environment In The Openings Of The Case-Screens Of Radio Electronic Means

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ABSTRACT

The paper presents the results of the study of the non-equilibrium function of the distribution of charged particles arising from the interaction of a powerful electromagnetic radiation (EMR) with the pre-ionized air in the openings of the case-screens of radio electronic means (REM) taking into account static and dynamic polarization. The indexes of the degree of the function of electron distribution, in which there are stationary non-equilibrium states of the electronic subsystem of the air in the small openings of the case-screens REM for two cases: in the case of the unobtrusive plasma and in the case of considering the collisions, have been found.

Key words: radio electronic means, electromagnetic radiation, ultrashort pulse duration, plasma protection technologies, gaseous plasma media.

1. INTRODUCTION

The implementation of protection of REM from a powerful EMR is possible on the basis of the usage of environmentally-friendly technologies, the usage of physical mechanisms of which will ensure the creation of the electro-sealed case-screens with respect to the powerful EMR ones. Plasma technologies which to the greatest extent meet the complex requirements for the means of protection can be used as such technologies.

The use of plasma technologies introduces a number of new protection properties to the means compared to conventional means. The most important of these is the instantaneous reaction of the state of the electronic subsystem, and, accordingly, the change in the electrophysical properties, which determine the reflecting, absorbing and locking properties of the protective means, under the influence of the pulse EMR of the ultrashort pulse duration (UPD), the efficiency throughout the lifecycle of the REM, the ability to withstand pulse surges.

1.1 Problem analysis

Determining the conditions for the protection of REM from the influence of the EMR is directly related to the determination of the main macroscopic parameters of the plasma medium that is artificially created and used to absorb, reflect or lock the EMR in openings, clefts or cable channels of input.

The scientific basis for the study of the macroscopic parameters of the plasma media in the openings, clefts or cable channels of the introduction of REM case-screens is the kinetic theory, the main achievements of which are associated with such prominent names in physics as Ginzburg, Boltzmann, Landau, Lenard, Balescu, Akiezer, Artsimovich, Sagdeev, Bogolyubov, Silin, Vlasov, Klimontovich, Kirkwood, Yvon, Fokker, Plank, and others.

The theory created by these prominent scientists is based on the research of the non-equilibrium states of the electronic subsystem of condensed medias that arise under the influence of ionization sources.

The peculiarities of non-equilibrium stationary processes in the conditions of constant sources of charged particles or energy have been investigated in a number of works by S. Moiseev, V.Karas, V. Novikov, A. Kats, V. Kontorovich, V. Yanovsky. In the works by V. Karas, I. Potapenko, it has been established that during the ionization of α-particles of the gas media stationary non-equilibrium states of the electronic subsystems that are found to be close to static appear, but the determination of the conditions for the formation of a high-speed electronic channel in openings, clefts or cable channels of the introduction of case-screens for the purpose of closue and the subsequent removal of the EMR, in particular, of the macroscopic parameters of the pre-ionized air media, require accurate knowledge of the degrees of the non-equilibrium distribution function.

The aim of the work is to investigate the function of splitting the charged particles of the strongly ionized air in the openings of the case-screens of REM under the influence of the UPD taking into account the collective processes.

2. MAIN MATERIAL

A strongly non-equilibrium state of the electronic subsystem of the air gap that is installed in the openings of small size RES under the influence of the EMR of the UPD leads to the evolution of the distribution function and, according to the formalized model of the process of formation of a high-frequency channel in the discharge gap [9,13], to the change in the concentration of the charged particles in the plasma-avalanche stage. At this stage, the temporal and spatial dependence of the particle distribution function is determined by the kinetic equations in which the collision integrals are due to the correlation between the particles.

Therefore, in studies it is impossible to limit the linear approximation. Taking into account the dynamic polarization of the plasma media, the kinetic equation with the Lenard-Balescu collision integral is the most adequate one for the description of the non-equilibrium state according to [4,13].

The dynamic polarization of the plasma leads to the weakening of the electric charge field in times [4]. If we neglect the effect of the dynamic polarization, that is, replace the dielectric constant with 1, then the collision integral of Lenard-Balescu transforms into the Landau collision integral.

According to the results of O. Sotnikov's work, it is advisable to study the relaxation of the electrons in the region of large energies by means of a nonlinear kinetic equation in the form of the law of conservation of the number of particles:

$$\frac{\partial f(p,t)}{\partial t} + \mathrm{div}(\vec{j}) = \psi\left(p, f(p,t)\right) \quad (1)$$

with the collision integral of Lenard-Balescu:

$$\begin{aligned} I_3 = {} & 2e^4 m \int d\vec{k} \frac{k_i k_j}{k^4} \frac{1}{\left|\varepsilon(\vec{k}\vec{v})\right|^2} \int d\vec{p}' f(\vec{p}') \delta\left(\vec{k}\left(\vec{p}-\vec{p}'\right)\right) \frac{\partial f}{\partial p_j} - \\ & -2e^4 m \int d\vec{k} \frac{k_i k_j}{k^4} \frac{1}{\left|\varepsilon(\vec{k}\vec{v})\right|^2} \int d\vec{p}' \frac{\partial f(\vec{p}')}{\partial p'_j} \delta\left(\vec{k}\left(\vec{p}-\vec{p}'\right)\right) f(p) \end{aligned} \quad (2)$$

where $\vec{p}$ – is the momentum vector.

The components of the vector of the particle flux of the charged particle in the phase space are determined by the diffusion tensor in the phase space D_{ij} and the friction force F_i [4].

Let us find the constituents of (2) for the static function.

$$\begin{aligned} & \int d\vec{p}' A p'^S \delta\left(\vec{k}\left(\vec{p}-\vec{p}'\right)\right) = \frac{A}{k} 2\pi \frac{1}{2} \int dp'^2_\perp \left(p_z^2 + p'^2_\perp\right)^{S/2} = \\ & = -\frac{2\pi A}{(S+2)k} \left|p_z\right|^{S+2} = -\frac{2\pi A}{(S+2)k} \left(\left|\frac{\vec{k}\vec{p}}{k}\right|\right)^{S+2}. \end{aligned} \quad (3)$$

$$\begin{aligned} & \int d\vec{p}' \frac{\partial f}{\partial p'_j} \delta\left(\vec{k}\left(\vec{p}-\vec{p}'\right)\right) = \frac{A}{k} \frac{1}{2} \int dp'^2_\perp \int dy S \left(p_z^2 + p'^2_\perp\right)^{(S-2)/2} p'_j = \\ & = -\frac{2\pi A}{k} \left|p_z\right|^S p_z \vec{e}_z = \\ & = -\frac{2\pi A}{k} \left(\left|\frac{\vec{k}\vec{p}}{k}\right|\right)^S \frac{\vec{k}\vec{p}}{k} \frac{\vec{k}}{k}. \end{aligned} \quad (4)$$

Now lets us determine the diffusion tensor in the phase space and the friction force:

$$\begin{aligned} F_i D_{ij} & = 2me^4 \frac{-2\pi A}{S+2} \int d\vec{k} \frac{k_i k_j}{k^5} \frac{1}{|\varepsilon|^2} \left|\frac{\vec{k}\,\vec{p}}{k}\right|^{(S+2)} = \\ & = -\frac{4\pi A m e^4}{S+2} \int d\vec{k} \frac{k_i k_j}{k^5} \frac{1}{|\varepsilon|^2} \left|\frac{\vec{k}\,\vec{p}}{k}\right|^{(S+2)}. \end{aligned} \quad (5)$$

$$\begin{aligned} F_i & = -2me^4 2\pi A \int d\vec{k} \frac{k_i k_j}{k^5} \frac{1}{|\varepsilon|^2} \left|\frac{\vec{k}\,\vec{p}}{k}\right|^S \frac{\vec{k}\,\vec{p}}{k} \frac{k_j}{k} = \\ & = -\frac{4\pi A m e^4}{p^2} \int \frac{d\vec{k}}{k^3} \frac{k_i}{k^4} \left(\frac{\vec{k}\,\vec{p}}{k}\right)^2 \left|\frac{\vec{k}\,\vec{p}}{k}\right|^S \frac{1}{|\varepsilon|^2} p_i. \end{aligned} \quad (6)$$

In order to calculate the integrals (5) and (6) in the isotropic case, we will use their tensor structure:

$$F_i = \alpha p_i, \qquad D_{ij} = \alpha \delta_{ij} + \beta p_i p_j, \quad (7)$$

where α и $\beta -$ are the unknown constants that need their definition.

To determine the scalar quantities α and β it is necessary to find the spur – Sp of these tensors and the convolution of the tensors with the impulses $p_i p_j$.

Using the tensor operations, we will obtain the following equations:

$$F_i=\alpha p_i,\quad p_i F_i=\alpha p^2,\quad \Rightarrow\ D_{ij}=\alpha\delta_{ij}+\beta p_i p_j .$$

$$3\alpha+\beta p^2=S_p D_{ij}\equiv J_1,\quad \alpha p^2+\beta p^4=p_i p_j D_{ij}\equiv J_2 .$$

$$2\alpha=J_1-\frac{J_2}{p_2};\qquad 2\beta p^4=3J_2-J_1 p^2 .$$

We will define the necessary scalar quantities α and β:

$$\alpha=\frac{J_1 p^2-J_2}{2p^2},\quad \beta=\frac{3J_2-J_1 p^2}{2p^4}. \tag{8}$$

As a result, we will write the expressions for D_{ij} and F_i:

$$D_{ij}=-\frac{2\pi mAe^4}{(S+2)p^2}\int\frac{d\vec{k}}{k^5}\left|\frac{\vec{k}\,\vec{p}}{k}\right|^{S+2}\times$$
$$\times\frac{1}{|\varepsilon|^2}\left\{\delta_{ij}\left[k^2p^2-\left(\vec{k}\vec{p}\right)^2\right]+\left[3\left(\vec{k}\vec{p}\right)^2-k^2p^2\right]\frac{p_i p_j}{p^2}\right\}, \tag{9}$$

$$F_i=-\frac{4\pi mAe^4}{p^2}\int\frac{d\vec{k}}{k^3}\left(\frac{\vec{k}\,\vec{p}}{k}\right)^2\left|\frac{\vec{k}\,\vec{p}}{k}\right|^S\frac{1}{|\varepsilon|^2}p_i . \tag{10}$$

1) If we neglect the dynamic polarization, then $\varepsilon=1$. In this case, the expression for the flow vector will look like this:

$$j_i=32\pi^2 mAe^4\lambda p^{2S+1}\frac{2S+5}{(S+2)(S+3)(S+5)}. \tag{11}$$

The determination of the divergence from the ration for the full particle flux (10) leads to the expression for the collision integral.

Taking into account that $f=AE^S=A(2m)^{-S}p^{2S}$, it is possible to find solutions that correspond to the constant of the particle flux in the phase space.

From the obtained correlations it is evident that there are two solutions:

$S_p=-5/2,\ S_e=-3/2$, which correspond to the constancy of the particle flux and the energy flux in the phase space.

In obtaining the abovementioned asymptotics, it has been assumed that the integral of collisions is convergent, both for large and for small values of the impulses.

Under conditions when $\omega\to 0$, or in the unobtrusive plasma, when the Debye shielding of a static longitudinal field occurs, the dielectric constant is determined according to the ratio:

$$\varepsilon=1+\frac{1}{k^2 r_Д^2}.$$

Let us determine the solution for this case.

$$D_{ij}=-\frac{2\pi mAe^4}{(S+2)}2\pi p^{S+2}\int dkk^2\int d\theta\sin\theta\frac{k^2}{k^5|\varepsilon|^2}|\cos\theta|^{S+2}\times$$
$$\times\left\{\delta_{ij}\left(1-\cos^2\theta\right)+\left(3\cos^2\theta-1\right)\frac{p_i p_j}{p^2}\right\}=$$
$$=-\frac{4\pi^2 mAe^4}{(S+2)}p^{S+2}\int\frac{dk}{k|\varepsilon|^2}\int d\theta\sin\theta\,|\cos\theta|^{S+2}\times$$
$$\times\left\{\delta_{ij}\left(1-\cos^2\theta\right)+\left(3\cos^2\theta-1\right)\frac{p_i p_j}{p^2}\right\}.$$

$$D_{ij}\frac{\partial f}{\partial p_j}=-\frac{4\pi^2 mAe^4}{(S+2)}p^{S+2}\times$$
$$\times\frac{1}{p}\frac{\partial f}{\partial p}2\int d\theta\sin\theta|\cos\theta|^{S+2}\cos^2\theta p_i\int\frac{dk}{k|\varepsilon|^2}= \tag{12}$$
$$=-\frac{16\pi^2 mAe^4}{(S+2)(S+5)}p^{S+2}\frac{\partial f}{\partial p}.$$

$$f(p)F_i=-4\pi^2 mAe^4 p^S 2\pi p_i\times$$
$$\times\int dk\frac{k^2}{k|\varepsilon|^2}\int d\theta\sin\theta\cos^2\theta|\cos\theta|^S f=$$
$$=-\frac{16\pi^2 mAe^4}{(S+3)}p^{S+1}f(p)\int\frac{dk}{k|\varepsilon|^2}\frac{p_i}{p}.$$

Taking into account (11), (12), we will obtain an expression for the flow vector:

$$j_i=16\pi^2 mAe^4 p^{S+1}\times$$
$$\times\int\frac{dk}{k|\varepsilon|^2}\left(\frac{f(p)}{S+3}-\frac{1}{(S+5)(S+2)}p\frac{\partial f}{\partial p}\right)\frac{p_i}{p}. \tag{13}$$

Taking into account the dynamic polarization, according to [4] $\varepsilon=\varepsilon\left(kv,k\right)$.

In case when it is necessary to take into account the collision ($\omega \;\square\; v_3$), the dielectric constant is determined according to the expression [7]:

$$|\varepsilon|^2 = \frac{\omega_p^2}{\omega^2} .$$

For this case, the components of the flow vector will be determined according to the following equations:

$$D_{ij}\frac{\partial f}{\partial p} = -\frac{4\pi^2 mAe^4}{(S+2)\omega_p^4 m^4}\int\frac{dk k^2 k^4 k^2}{k^5}\times \\ \times\int d\theta\sin\theta|\cos\theta|^{S+2}2\cos^2\theta\cos^4\theta . \qquad (14)$$

$$\frac{1}{p}\frac{\partial f}{\partial p}p_i = -\frac{16\pi^2 mAe^4}{4(S+2)\omega_p^4 m^4}p^{S+6}\frac{\partial f}{\partial p}\frac{k_{max}^4}{(S+9)}\frac{p_i}{p} . \qquad (15)$$

$$F_i f(p) = -\frac{4\pi mAe^4 2\pi}{4\omega_p^4 m^4}\times \\ \times k_{max}^4 p^{S+5}\int d\theta\sin\theta\cos^2\theta|\cos\theta|^{S+4} f(p)\frac{p_i}{p} = \\ = -\frac{4\pi^2 mAe^4}{\omega_p^4 m^4}k_{max}^4\frac{p^{S+5}}{S+7}f(p)\frac{p_i}{p}.$$

According to the obtained rations, the flow vector will be determined by the following equation:

$$j_i = \frac{8\pi^2 mA^2 e^4 k_{max}^4}{\omega_p^4 m^4}p^{2S+5}\left(\frac{2S+9}{(S+2)(S+7)(S+9)}\right) . \qquad (16)$$

It is seen that in this case there are two solutions: $S_p = -7/2$, $S_e = -9/2$, that correspond to the constancy of the particle flux and the energy flux in the phase space.

5. CONCLUSION

As a result of the research conducted, we have defined the influence of the non-equilibrium state of the electronic subsystem of the air media in the opening of the case-screen REM on the character of the distribution function for a nonhomogeneous plasma taking into account the static and dynamic polarization of the media, the relaxation of the electrons, and also the collective interaction of the particles not only due to the direct collisions, but also due to the influence of the EMR of the UPD. The indexes of the degree of distribution of electrons s, in which the stationary non-equilibrium states of the electronic subsystems of the air media of small-sized openings, clefts or case-screens or cable channels of the introduction, both taking into account the dynamic polarization and without it, have been determined.

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