EXCITATION OF ALTERNATING CURRENT IN QUASISTATIC SYSTEMS BY MOTION OF AN IONIZED MEDIUM

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We discuss the possibility of exciting an alternating current by means of an interaction between an electric field of a quasi-static system (in particular, the field of a parallel-plate capacitor) with a moving ionized medium. In the case of negative energy dissipation of the electric field (EDEF) of such a system in the moving medium, its combination with a resonant system (tank circuit) can be used to generate alternating current (compare with a monotropic generator). We discuss in this paper the conditions under which negative EDEF is possible in a moving conducting gas (liquid) and in a cosmic plasma.

1. Let a dense ionized gas move with velocity v = const. We consider the case most favorable for our purposes, when the variation of the degree of ionization, diffusion, etc. can be neglected. Let the conductivity of the gas be σ_0. In a moving gas the current density is

$$\mathbf{j} = eN\mathbf{v}_\sim + en_\sim\mathbf{v} = \sigma_0\mathbf{E} + \mathbf{v}\,\mathrm{div}\,\mathbf{E}/4\pi,$$

where $\mathbf{v}_\sim$, $n_\sim$—respectively the perturbations of the velocity and density of the carriers in the electric field E, e—carrier charge, N—unperturbed density of the carriers. For a potential electric field E, $\mathbf{j} \sim e^{i\omega t - i}$ the EDEF (energy dissipation of the electric field) per unit volume is

$$Q = \mathbf{jE} = \sigma_0/(1 - \mathbf{kv}/\omega)\,|E|^2,$$

k—wave vector of the electric field. Consequently, the values $Q < 0$ occur for slow ($\omega < \mathbf{k}\cdot\mathbf{v}$) harmonics of the electric field[1)]; they are due to the work performed by the convection current $en_\sim\mathbf{v}$[3,4].

The simplest example of a quasistatic system for which negative EDEF is possible[2)] is a parallel-plate (with grids as plates) capacitor, consisting of two interconnected grids and a third grid placed halfway between them, through which a moving conductor passes. At frequencies $\omega \gg \sigma_0$, when the field in the capacitor is weakly disturbed by the moving conductor, the resistance of the capacitor can be readily determined, for example, from the EDEF. It equals

$$R = \frac{2\pi L}{\omega S}\frac{4\pi\sigma_0}{\omega}f(\theta), \quad f = 1 + \frac{\sin 2\theta - 4\sin\theta}{2\theta}, \quad \theta = \frac{\omega L}{v},$$

L—distance between grids, S—area of the grids. It is easy to verify that $R < 0$ when $\theta < 2$.

In one-dimensional grid systems with a "running" distribution of the charge negative EDEF is possible also when $\omega \ll \sigma_0$. Thus, in an electric field produced by a one-dimensional discrete charge distribution,

$$\rho = \varkappa\{\delta(x) + i\delta(x - L) - \delta(x - 2L) - i\delta(x - 3L)\}e^{i\omega t},$$

$\varkappa$—charge per unit area, negative EDEF is possible even when $L \gg l = v/\sigma_0$ (see below).

To estimate the efficiency η of generators using the foregoing systems, we take into account the fact that the negative EDEF should decrease in magnitude in an electric field E_0 that changes the carrier velocity by an amount on the order of the gas velocity v. Introducing the carrier mobility μ, we obtain $E_0 \approx v/\mu$. Then the generated power is $W \approx \sigma_0 LSE_0^2$. At $\sigma_0 \approx \omega \approx v/L$ we get

$$W \approx \frac{SNv^3\nu^2}{\omega_0^2}, \quad \eta = \frac{W}{{}^1/_2 N_0SMv^3} \approx \frac{N}{N_0}\frac{\nu^2}{\omega_0^2}\frac{m}{M};$$

ν, ω_0, N, m—respectively the collision frequency, the plasma frequency, the density and mass of the carriers, N_0, M—density and mass of the neutrals. This estimate is maximal also in other cases ($\omega \gtrless \sigma_0$, $L \gtrless v/\sigma_0$). Under favorable conditions (ionic conductivity, increased values of the collision cross sections, increased neutral densities; multigrid systems), the estimate for η can be "stretched out" to unity. Thus, $\eta \sim 1$ when $v \sim 10^5$ cm/sec if $\omega \sim \sigma_0 \sim 10^5\ \mathrm{sec}^{-1}$, the cross section is $Q_0 \sim 10^{14}\ \mathrm{cm}^2$, the temperature is $T \sim 10^{3\circ}$ K, and the total length of the system is approximately 20 meters.

2. If the parameter v/σ_0 is sufficiently small, then to determine the EDEF it is necessary to take into account the character of flow of the moving liquid (gas) around the bodies that limit (guide) its motion. A sufficiently general answer to the question of the possibility of negative EDEF under such conditions is, of course, difficult.

However, for an incompressible conducting liquid (carrier density constant, div v = 0) it is possible to determine relatively simply the sign of the EDEF as $v/\sigma_0 \to 0$. Indeed, in this case the equation for the perturbation of the carrier density $n_\sim$ takes the form ($n_\sim \sim e^{i\omega t}$)

$$i\omega n_\sim + 4\pi\sigma_0 n_\sim + \mathbf{v}\nabla n_\sim = 0,$$

from which it follows that $n_\sim$ differs noticeably from zero at distances $l \lesssim v/\sigma_0$ from the boundary of the moving conductor. Inasmuch as the negative EDEF is connected with the work of the convection current $en_\sim v_0$, it follows that to determine its possibility it is sufficient to confine oneself to an investigation of the EDEF in the region near the boundary of the moving liquid conductor.

1)The electroacoustic instability is connected with this circumstance [1,2].

2)The possibility of exciting an oscillator moving in the medium with absorption was discussed in the diploma thesis of Yu. S. Chertkov, written under the guidance of A. V. Gapanov (Gor'kii University, 1966).

Under these conditions the boundary can be regarded as flat, and the electric field (outside the conductor) can be regarded as homogeneous. If we assume that the conducting liquid flows away from the flat boundary (this corresponds to conditions occurring in the region of detachment of a jet of conducting liquid), then it can be shown that the EDEF is positive; on the other hand, if the velocity of the liquid conductor is parallel to the boundary, then the EDEF can be negative also in values $V \gg (v/\sigma_0)^3$. Negative values of EDEF in the latter case are due to the work of the convection surface current; for its realization it is necessary that the surface charge take part in the motion of the conductor—roughly speaking, it is necessary that the "dimension" of the surface charge (on the order of the Debye radius δ) be large compared with the thickness of the boundary layer. We note in this connection, that a direct utilization of the considered effects in hydroenergetics is apparently impossible, for even in the case of distilled water ($\sigma_0 \sim 10^6$ sec^{-1}) at $v \sim 10^3$ cm/sec the values $l \sim 10^{-2}$ and $\delta \sim 10^{-4}$—10^{-5} cm (with account of the dielectric constant of the water, $\epsilon \sim 80$) are quite small.

3. In quasistatic systems penetrated by beams of a rarefied plasma (owing to the customarily prevalent condition $v \ll v_{Te}$, $v_{Te} = \sqrt{2T/m}$—thermal velocity of the electrons), the negative EDEF is prevented by the electron absorption (ions, whose thermal scatter is small, can make a negative contribution to the dissipation (see[5])). Thus, for the capacitor considered above, located at the solar center (on the earth's orbit), at an electron temperature $T \sim 10^{6\circ}$K, calculation shows that negative dissipation at frequencies $\omega \gg \omega_0$ where ω_0 is a plasma frequency of the electrons, is possible only at $v < 550$ km/sec even under conditions when the electron density in the capacitor is smaller by a factor $2v_{Te}/v$ than the unperturbed density owing to the static potential of the capacitor, due to the absorption of the charged particles. On the other hand, for a simple parallel-plate capacitor, negative EDEF is impossible under these conditions[5].

However, the electron density near a capacitor located at the solar center (where the Debye radius is relatively large), can be decreased also artificially by producing around the capacitor a high-frequency electric field that repels the electron as a result of the averaged force[6,7]. Under these conditions, the electron absorption is small and a negative EDEF is possible.

On the other hand, for a capacitor traveling in the earth's ionosphere, the electron absorption can be small when the capacitor moves across the earth's magnetic field (the capacitor grids are parallel to the magnetic field) at frequencies $\omega \ll \omega_H$, where ω_H is the gyrofrequency of the electrons, although a realization of this case may be hindered by the possible difference between the structure of the electric field in the capacitor and in vacuum (see[8]).

We point out, however, that the powers that can be obtained from a unit area of such systems are much smaller than the power obtained from solar batteries, since the energy fluxes of the cosmic plasma (up to 10 erg-cm^{-2} sec^{-1}) are much smaller than the flux of electromagnetic radiation from the sun ($\sim 10^6$ erg-cm^{-2} sec^{-1}).

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