COMPUTER SIMULATION OF THE PARTICLE ACCELERATION IN PULSAR MAGNETOSPHERES

YU. A. RYLOV

Institute of Mechanics Problems, Moscow, U.S.S.R.

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Abstract. In the spherically-symmetric case, a computer simulation of the electron acceleration inside the outflow channel of the pulsar magnetosphere is produced. The stationary motion of electrons is shown to be unstable in the case of $\alpha > \alpha_c$, where $\alpha$ is a parameter describing inhomogeneity of the background charge, and $\alpha_c$ is its critical value. The arising non-stationary motion of electrons leads to a formation of electron bunches, which move chaotically. The mean electron energy appears to be much greater at the non-stationary motion, than at the stationary one. The time-averaged parameters of the non-stationary electron flow and their dependence upon $\alpha$ have been investigated. Distributions of the mean values of parameters (charge density, electron velocity, electric field energy density, pressure, and internal energy of the gas composed of the electron bunches) over the magnetosphere altitude have been investigated. The mean spectra of the charge density have been obtained. The results of numerical investigation of the spherically-symmetric model are used for estimation of the electron energy and of the electron flux in the case of the more realistic model. The radioemission loss is estimated, and is shown to be large enough for explaining the radiopulsar phenomenon as a thermal radioemission of the pulsar magnetosphere. In particular, such common properties of the pulsar radioemission as the high bright temperature, the sharp radioemission directivity, and the characteristic turn-over of the radioemission spectrum at the frequency of the order $10^8$ Hz are found a natural explanation in frames of this model.

1. Introduction

The problem of particle acceleration in the axially-symmetric pulsar model is considered. Stationary models of the particle acceleration were considered in papers by Sturrock (1971), Michel (1974, 1975), Tademaru (1973, 1974), Fawley et al. (1977), Scharlemann et al. (1978). The potential distribution inside the outflow channel, where the particle are accelerated, has been calculated for these models. The statement of the problem in different papers is not the same, but everywhere their authors tended to obtain particle acceleration considering the electric field only inside the outflow channel. The charge distribution outside the outflow channel has been completely ignored. Mathematically, it meant a statement of uniform boundary conditions for potential at the boundaries of the outflow channel. Such a statement of the problem is in principle incorrect. A stationary particle acceleration, however, arise only in an electrical field of charges which are external with respect to the outflow channel. This must be taken into account by means of non-uniform boundary conditions. Stationary acceleration by the electric field of charges, which are placed inside the outflow channel, is not impossible. This was shown in papers of Tademaru (1973, 1974). In the example of a spherically-symmetric model it was also shown in the paper by Rylov (1979). In papers by Fawley et al. (1977) and Scharlemann et al. (1978) the particle acceleration resulted from the incorrectness...
of the boundary condition at the infinite boundary of the outflow channel. The boundary conditions have the form

\[ \lim_{r \to \infty} \frac{\partial \Phi}{\partial r} = 0, \quad \Phi|_\Sigma = 0, \]

(1.1)

where \( \Phi \) is the potential, \( \Sigma \) is the finite boundary of the outflow channel: the stellar surface plus the last closed magnetic line. The boundary conditions (1.1) do not provide the sole solution of the Poisson's equation, because the total charge of the system remains indefinite. For the uniqueness of the solution the first condition (1.1) should be written in the form

\[ \lim_{r \to \infty} r^2 \frac{\partial \Phi}{\partial r} = -f(\phi, \varphi), \]

(1.2)

where \((r, \phi, \varphi)\) are spherical coordinates, \(f\) is a given function; the total charge of the system being

\[ Q = \frac{1}{4\pi} \int \int f(\phi, \varphi) \sin \phi \, d\phi \, d\varphi. \]

(1.3)

The absence of the uniqueness of the solution is masked by using the Green function. The solution is represented in the form (formula (22) of the paper by Fawley et al., 1977)

\[ \Phi(x) = \int \int \left[ \eta(x') - \eta_R(x') \right] G(x, x') \, d^3x' + \frac{1}{4\pi} \int_{\Sigma} \int_{\Sigma_\infty} \left( G \frac{\partial \Phi}{\partial n'} - \Phi(x') \frac{\partial G'}{\partial n'} \right) \, dS', \]

(1.4)

where \( G(x, x') \) is the Green's function, which satisfies the boundary conditions of the form (1.1), and \( \Sigma_\infty \) is the sphere \( r = R = \text{const.}, R \to \infty \). The surface integral is omitted because of the boundary conditions (1.1). But, in fact, only the surface integral over finite surface \( \Sigma \) vanishes. The integral over infinite sphere \( \Sigma_\infty \) does not, in general, vanish because the first condition (1.1) and the similar condition for \( G \) are too weak. For the vanishing of the integral, the condition of the form (1.2) with \( f(\phi, \varphi) = 0 \) must be fulfilled. The Green's function \( G \) does not satisfy, in general, the condition (1.2) with \( f(\phi, \varphi) = 0 \).

As a result one can add the term

\[ \lim_{r' \to \infty} \int_0^\pi \sin \theta' \, d\theta' \int_0^{2\pi} d\varphi' \left( G \Psi_1(\theta', \varphi') - \Psi_2(\theta', \varphi') \frac{\partial G'}{\partial r'} \right) \]

to the solution

\[ \Phi(x) = \int \int \left[ \eta(x') - \eta_R(x') \right] G(x, x') \, d^3x', \]

(1.5)