A linotron is considered, which is a linear accelerator with repeated use of the accelerating system because electrons are reflected from magnetic mirrors placed on both sides of the waveguide. The mirror field consists of a field with a plug configuration and a spiral field. Numerical studies have been made on the dynamics of particles in such a field for various energies.

Magnetic-braking synchrotron radiation is generated by relativistic charged particles moving with acceleration along a curvilinear path, including electrons moving in a circular orbit [1, 2]. It was first observed in 1947 by Pollak in a synchrotron (which is why it is called synchrotron radiation) for an electron energy of 70 MeV as a bluish-white radiation so bright that it was visible even in daylight. The general use of synchrotron radiation in science and engineering has stimulated research on upgrading existing sources and creating new ones. An important feature of synchrotron radiation is that its characteristics are predictable theoretically and allow of exact quantitative description. A general equation has been derived [1] for the power in the synchrotron radiation emitted by an ultrarelativistic particle with energy \( E \) that moves in a circular orbit of radius \( R \).

The particle moves with a constant velocity and radiates the following power in the entire orbit within a wavelength range \( d\lambda \) and a range \( d\theta \) in the planar angle \( \theta \) (Fig. 1):

\[
\omega(\lambda, \theta) = \frac{27e^2c}{32\pi^3R^2} \left( \frac{\lambda_c}{\lambda} \right)^4 \gamma^2 \left[ 1 + (\gamma\theta)^2 \right]^2 \left\{ K_{2/3}^2(\xi) + \frac{(\gamma\theta)^2}{1 + (\gamma\theta)^2} K_{1/3}^2(\xi) \right\},
\]

where \( e \) and \( m \) are the charge and mass of the particle, \( c \) is the velocity of light, and \( \lambda_c \) is the critical wavelength:

\[
\lambda_c = \frac{4\pi R}{(3\gamma^3)};
\]

with \( \gamma = E/mc^2 \) the relativistic factor, \( \theta \) the angle between the emission direction and the plane of the orbit, and \( K_{1/3} \) and \( K_{2/3} \) are modified Bessel functions of the second kind with argument \( \xi = \frac{\lambda_c}{2\lambda_c} \left[ 1 + (\gamma\theta)^2 \right]^{3/2} \).

Here (1) gives the spectrum and the angular distribution of the emission from an ultrarelativistic particle. It follows from (2) that the higher the energy, the shorter the emission wavelength, and the spectrum is almost continuous. The wavelength at which the spectral maximum occurs is related to the critical wavelength by \( \lambda_m = 0.42\lambda_c \).

The main sources of synchrotron radiation are cyclic electron accelerators (synchrotrons) and also storage rings, in which the radiation is generated near the rotation magnets. The emission causes energy loss from the particles, and that circumstance in the first case sets a limit to the energy of the electrons attainable in a synchrotron at about 300 MeV, while in the second it makes additional acceleration necessary.

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A linotron with spiral undulator as a synchrotron radiation source

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UDC 621.384.6

A linotron is considered, which is a linear accelerator with repeated use of the accelerating system because electrons are reflected from magnetic mirrors placed on both sides of the waveguide. The mirror field consists of a field with a plug configuration and a spiral field. Numerical studies have been made on the dynamics of particles in such a field for various energies.

As a rule, basic synchrotron radiation sources are cumbersome and expensive equipments and are used mainly for research. For work of applied character, one requires compact and comparatively cheap sources. This makes it interesting to consider sources based on traditional linear accelerators.

A major advantage of a linear accelerator of resonance or waveguide type relative to accelerators with circular charged-particle motion is that there is no loss by radiation because of the rectilinear motion of the particles and the slight effect of the acceleration. Linear accelerators have traditionally been used to produce electrons of the high energies required by particle physics. The maximum energy in a linear accelerator is determined by the strength of the magnetic field and the length of the accelerator. For example, the linear accelerator at Stanford in the USA with an energy of 4 GeV has a field strength of 100 kV/cm and a length of 4 km. A linear accelerator is usually split up into sections of length 4 m, which are fed from power klystrons in the centimeter wavelength range. The sections are cylindrical waveguides loaded by diaphragms. The sections must be very accurately manufactured. This single use of an accelerating section in a linear accelerator substantially increases the size of the machine and the working costs, in contrast to the cyclic acceleration method. Therefore, to provide repeated beam acceleration in a single accelerating device has led to the repeated consideration of schemes providing beam recirculation in a linear accelerator [3–6]. For example, an accelerator for medical purposes [4] used double acceleration in the same accelerating waveguide by the use of a magnetic mirror. The entry of the particles into the accelerating phase of the field on reflection from the mirror was regulated by moving the coils mechanically. Unfortunately, that scheme is applicable only for low recirculation numbers.

An accelerator of linotron type can be a magnetic-braking radiation source [4–7], in which the cavity or waveguide section acting as the linear accelerator is placed between two magnetic mirrors, which recirculate the electron beam in the linear accelerator and provide conditions for generating the radiation because of the field inhomogeneity at the ends of the accelerating section, while the electric field in the cavity or waveguide balances out the energy loss due to emission and provides additional acceleration. Then the middle of the device acts as a linear accelerator, while the ends act as radiators and can be used as synchrotron radiation sources. Figure 1 shows the scheme for such a source, with coils for producing the magnetic fields, the electron path, and the synchrotron radiation propagation direction.

In all linotron schemes, the beam is returned by magnetic mirrors having azimuthally symmetrical magnetic fields. In such a field, there is no transverse component at the axis, so the field must be very strong in order to reflect relativistic particles. Also, the radius of the particle orbit at the point of reflection increases in proportion to the momentum, which increases the dimensions of the entire accelerating device.

To reduce the dimensions of the device, we examine how particles with various energies are affected by a magnetic field that is the sum of three fields: a homogeneous field; an azimuthally symmetric one increasing along the axis of motion (a plug configuration field); and with spiral symmetry, namely azimuthally unsymmetrical. The spiral field is the new factor