Relativistic-electron radiation in a weak magnetic field with sharp boundaries

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The spectral-angular and energy dependences of relativistic-electron radiation in a weak magnetic field with sharp boundaries have been investigated experimentally. The electron radiation in the long-wave region of the spectrum has a high intensity and directivity in such a field.

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A radiation, whose properties compare favorably with those of synchroton radiation, has been produced by using a special magnetic device placed in the orbit of a cyclic accelerator.[1] A transverse, periodic, magnetic field formed in this device and in similar devices made it possible to generate an intense, monochromatic, short-wave radiation. Weak magnetic fields of one polarity can be used effectively to increase the radiation intensity in the long-wave region of the spectrum.

The electron radiation in such a magnetic field, when the angle of rotation α is small compared with the characteristic emission angle $1/\gamma$, where $\gamma=(1-\beta^2)^{-1/2}$, $\beta=v/c$, and v is the particle velocity, was studied theoretically in Refs. 2-7.

It follows from the results of a theoretical study that the radiation properties of relativistic electrons in this case differ substantially from those of synchrotron radiation (SR) ($\alpha \gg 1/\gamma$).

If the dipolarity ($\alpha \ll 1/\gamma$) is satisfied, then the shape of the radiation pulse in the direction determined by the angle θ relative to the particle trajectory will follow the magnetic-field variation along its trajectory, and its duration will be $\Delta t=(L/c)(1-\beta\cos\theta)$, where L is the range of the field.

If the magnetic field has sharp boundaries, i.e., the field edges are close to each other $L/H_m\ \partial H/\partial Z \gg 1$, where H_m is the field amplitude and Z is the direction of motion of the particle, then the spectral-angular distribution of the radiation intensity will have a sequence of minima and maxima whose location is determined by the relations

$$\frac{L(1+\theta^2\gamma^2)}{2\lambda\gamma^2}=\begin{cases} k, & \text{min} \\ \dfrac{2k+1}{2}, & \text{max} \end{cases} \quad \begin{pmatrix} \theta << 1 \\ \gamma >> 1 \end{pmatrix}, \tag{1}$$

where $k=1,2,3,\ldots$ and λ is the observed radiation wavelength. Specifically, a ring-shaped structure can appear in the angular distribution of the radiation at a given

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wavelength under certain conditions.

In this paper we present the first results of experiments on electron radiation in a weak magnetic field. The experiments were performed using the "Pakhra" synchrotron. The electron energy was raised to 850 MeV.

In our experiments the required magnetic field was formed in the accelerator's straight section by using two rectangular windings of length $L = 100$ cm. The region of magnetic-field buildup was equal to ~10 cm. The magnetic field excited by the winding in the synchrotrons's orbit was oriented parallel to the orbit plane.

The field was excited by a trapezoidal pulsed current; the leading edge of the current pulse was ~1 msec and its flat peak was ~2 msec. The accuracy of current stabilization at the flat peak was better than 0.3%.

For the selected orientation of the excited magnetic field the electron-radiation field vector was directed principally at right angles to the orbit plane of the synchrotron (π component). On the other hand, the electric-field vector of the synchrotron radiation from the accelerator magnet was oriented mainly in the orbit plane (σ component). We have therefore excluded in our experiments the π component of radiation in order to reduce substantially the background due to SR.

The angular distribution of the electron-radiation intensity was studied by using a photographic method. The photographic materials were placed in the focal plane of the objective lens. The radiation at a fixed wavelength was separated out by an interference light filter ($\lambda_f = 5040$ Å, $\Delta\lambda/\lambda_f = 2.2\%$). The pulsed magnetic field in the winding was turned on after the electrons had reached the maximum energy ($E_m = 850$ MeV); this almost eliminated the electron-energy variation during exposure of the photographic plates. The magnetic-field amplitude was equal to $H_m = 26.6$ Oe.

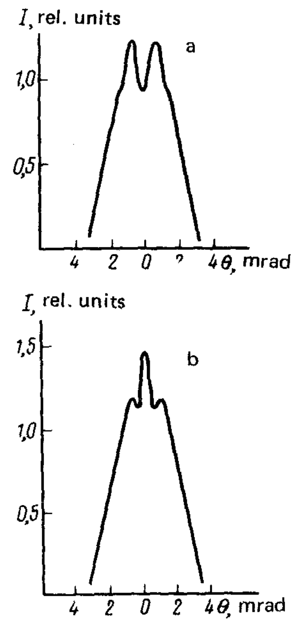

FIG. 1. Vertical-angular distribution of the intensity of radiation in the direction of the axis of the straight section of the synchrotron (π component). (a) In the absence of a field in the winding; (b) in the presence of a field in the winding.

The radius of curvature of the electron trajectory in this case was equal to ~1 km.

The distribution of the intensity of radiation in the vertical plane from the bending magnets of the synchrotron in the direction of the axis of the straight section is shown in Fig. 1a. This figure also shows the minimum of the intensity of radiation in the electron-orbit plane, characteristic of the π component. We should mention that the maximum radiation intensity in Fig. 1a exceeds noticeably the corresponding intensity of uniform fields of the bending magnets, consistent with Refs. 8 and 9.

The radiation picture changed dramatically when the field in the winding was turned on (Fig. 1b). As expected, the minimum (Fig. 1a) was replaced by a narrow peak with a width ~1 mrad. This indicates that the radiation in question had a higher directivity.

The dependence of radiation intensity at zero angle ($\theta = 0$) on the electron energy was investigated by us using the FEU-93 photomultiplier. The energy of the radiating electron was varied by shifting the pulse excited in the magnetic-field coil during the acceleration cycle. A dependence (curve 1) obtained in this manner with a coil field $H_m = 19.9$ Oe is shown in Fig. 2. We can see in Fig. 2 that this dependence has an oscillating nature in the energy range 400 to 600 MeV. The radiation intensity increases monotonically at energies above 600 MeV. The location of the maxima and minima of the radiation intensity is in satisfactory agreement with the relation (1). A certain disparity can be attributed to electron radiation in the bending magnets, to the finite range of the spectral sensitivity of the photomultiplier (3800 Å $\leqslant \lambda \leqslant$ 4800 Å), as well as to a minor violation of the radiation dipolarity in our experiments.

For a comparison, the intensity of electron radiation in the edge fields of the bending magnets is represented by curve 2 in Fig. 2. We can see that the instantaneous spectral-angular radiation intensity is much higher than the synchrotron radia-

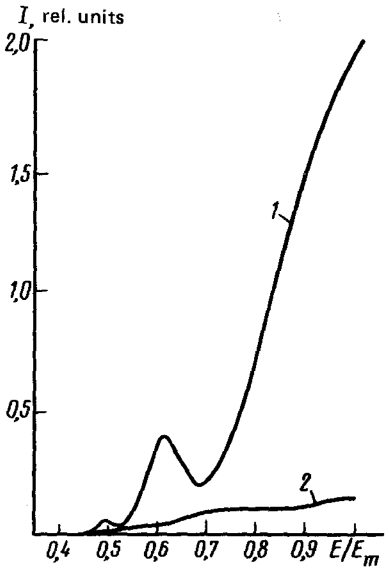

FIG. 2. Dependence of the radiation intensity on the electron energy (π component). 1–In the presence of a field in the winding; 2–in the absence of a field in the winding.

tion intensity after the coil's field is turned on.

The unambiguous dependence of the location of the sharp maxima (or minima) on the particle energy, which is vividly displayed by curve 1, can be used to measure effectively and with great precision the energy of accelerated particles. The observed energy dependence of the radiation intensity, in principle, should allow an induced radiation to be generated in such a system.

Thus the electron radiation in a weak magnetic field with sharp boundaries has a high intensity and directivity in the long-wave region of the spectrum, as well as many other attractive features for practical applications.

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1. D. F. Alferov, Yu. A. Bashmakov, K. A. Belovintsev, E. G. Becconov, and P. A. Cherenkov, Pis'ma Zh. Eksp. Teor. Fiz. **26**, 525 (1977) [JETP Lett. **26**, 385 (1977)].
2. L. D. Landau and E. M. Lifshitz, Teoriya polya (Field Theory), Nauka, Moscow, 1967.
3. D. F. Alferov, Yu. A. Bashmakov, and E. G. Bessonov, Zh. Tekh. Fiz. **42**, 1921 (1972) [Sov. J. Tech. Fiz. **17**, 1540 (1972)].
4. Yu. A. Bashmakov, Thesis FIAN, 1978.
5. R. Coisson, Phys. Rev. A **20**, 524, (1979).
6. V. G. Bagrov, M. B. Moiseev, M. M. Nikitin, and N. I. Fedosov, Izv. VUZov (University Bulletin), Physics, No. 5, 125, 1980.
7. E. G. Bessonov, Zh. Eksp. Teor. Fiz. **80**, 852 (1981).
8. Z. L. Artem'eva, E. M. Moroz, and K. N. Shorin, Brief Communications in Physics, No. 7, 36, 1980.
9. M. M. Nikitin, A. F. Medvedev, MoB. Moiseev, and V. Ya. Epp, Zh. Eksp. Teor. Fiz. 79, 763 (1980) [Sov. Phys.–JETP **52**, 388 (1980)].

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