Nuclear Instruments and Methods in Physics Research A304 (1991) 63-65
North-Holland

Observation of mutual coherence of spontaneous radiation from two undulators separated by an achromatic bend

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A method of extracting radiation from the optical cavity of a free electron laser using an insignificant bend of the electron beam is discussed, noting that the modulation of its longitudinal density needs to be conserved. Modernization of the optical klystron magnetic system of the VEPP-3 storage ring has made it possible to realize an achromatic bend of electrons between two undulators. In such a case the mutual coherence of the radiation from the undulators has been demonstrated by means of Young's interference experiment. The experimental results confirm the possibility of implementing the suggested technique for radiation extraction.

A problem which arises when creating high-power free electron lasers (FELs) is the extraction of radiation from an optical cavity. One way to solve this problem was suggested in the Institute of Nuclear Physics, Novosibirsk, in 1987, and was called "electron extraction of radiation" [1]. In essence, the electron beam is deflected from the optical axis of the cavity at a small angle and passed through an additional undulator (fig. 1). Since the longitudinal density of the electrons at the exit of the FEL is modulated at the radiation wavelength, the additional undulator becomes a source of coherent radiation that passes around the front mirror of the optical cavity and exits the cavity. To conserve the modulation of the longitudinal density at the bend, the achromaticity of the bending magnetic system is important. The "electron extraction of radiation" offers the possibility of largely reducing the radiation power inside the optical cavity as compared with the extracted power. In "conventional" lasers this relation is always inverse. In fact, in the scheme under discussion, the FEL serves only for microbunching the electron beam, while the coherent radiation of electrons in the additional undulator is utilized.

The density modulation conservation condition at the bend is the same as the coherence condition for spontaneous radiation from two undulators, with one positioned before the bend, and the other after it [2]. In view of this, and to check experimentally the feasibility of the "electron extraction" scheme [3], we have em-

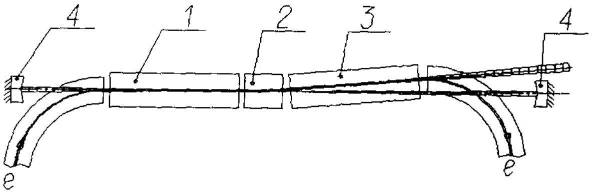

Fig. 1. Electron extraction of radiation: 1 – magnetic FEL system, 2 – bending magnetic system, 3 – additional undulator, 4 – mirrors of the optical cavity.

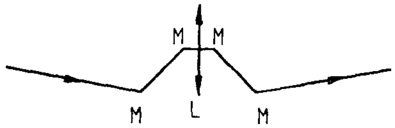

Fig. 2. A schematic view of the achromatic bend: M – bending magnets, L – lens.

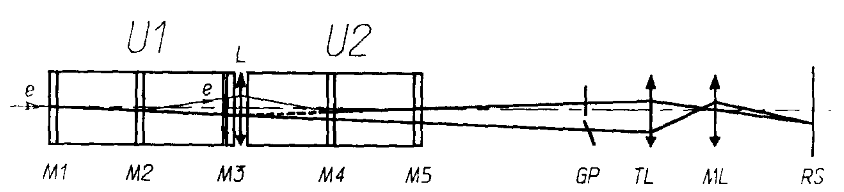

Fig. 3. The scheme to observe radiation coherency at the achromatic bend of electrons in the magnetic system of the optical klystron on VEPP-3: $M1$–$M5$ – horizontal bending correctors; L – quadrupole lens focusing in horizontal direction; $U1$ and $U2$ – undulators of the OK magnetic system; TL and ML – optical telescope lens and imaging lens respectively; RS – registering screen (Micrat or a one-dimensional CCD structure).

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ployed the OK magnetic system which is in use at the VEPP-3 storage ring [4,5].

We have chosen a scheme consisting of four short magnets and a focusing lens (fig. 2). Since there is not sufficient free space between the undulators, half of each undulator is used for the achromatic bend (fig. 3), i.e. in the middle of each undulator, U1 and U2, we placed the steering coils M2 and M4, each being able to bend electrons by a maximum angle of 4 mrad. Between the undulators, close to the magnetic buncher we place a quadrupole lens, which focuses in the achromatic bend plane (i.e. along the horizontal) with a focal length of $F = 360$ cm. The steering coil M3 of the magnetic buncher is used instead of the two middle magnets shown in fig. 2. Thus, the magnets which produced the η-function in the lens, are half the undulator length ($L = 3.4$ m) apart, i.e. they are 1.7 m apart. In accordance with the focal length of the lens, the maximum possible angle of the achromatic bend (limited by the deflection angle of the steering coils) is $\theta_B = 2$ mrad. The diffraction angular divergence of the radiation emitted from the undulator of length L is

$$\sqrt{\lambda/(L/2)} = \sqrt{0.63\ \mu\text{m}/1.7\ \text{m}} = 0.6\ \text{mrad}$$

for $\lambda = 0.63$ μm. To compensate for the time delay of the radiation from two undulators, we used two flat-parallel plates (see fig. 2) of $d = 2.75$ mm thickness; one is placed normal to the radiation from the nearest

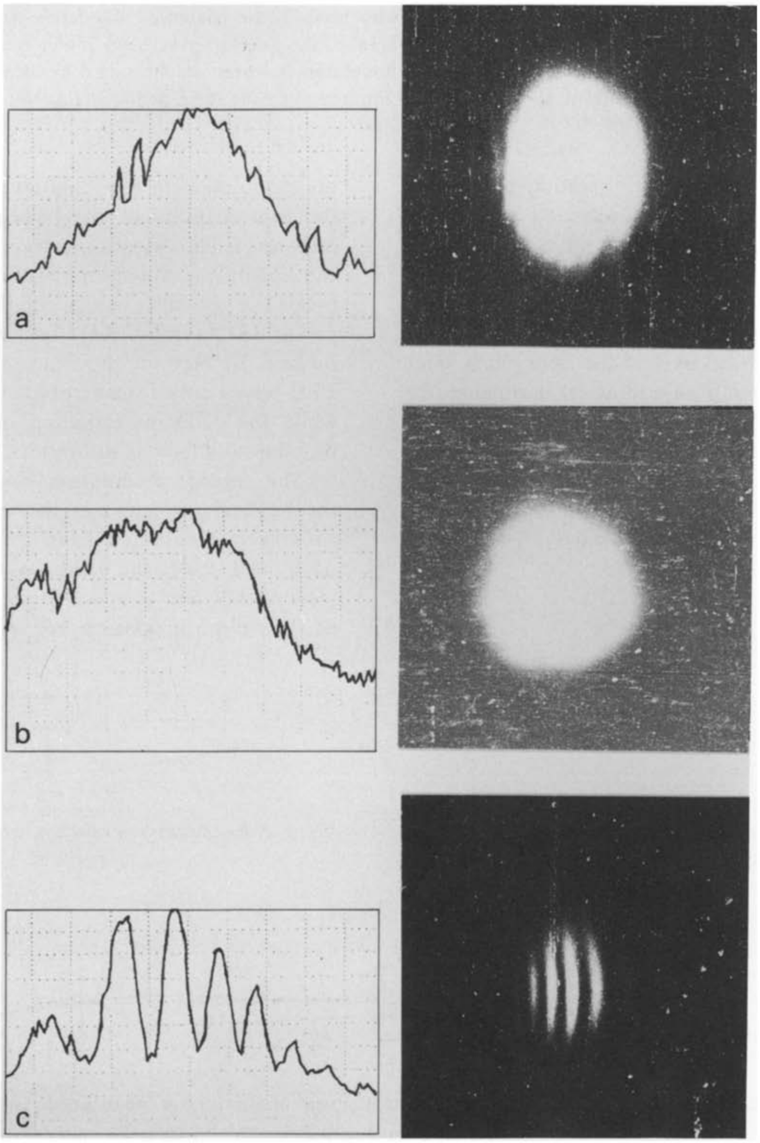

Fig. 4. Interference pictures observed at a conventional (nonachromatic) bend (a), at an achromatic bend without the delay compensation (b) and with the delay compensation (c) (registered by Micrat on the right and by a CCD structure on the left).

undulator, while the other is placed at an angle of $\theta \approx 20°$ to the radiation from the distant undulator; this corresponds to an optical path difference of

$$\delta = d\left(\sqrt{n^2 - \sin^2\theta} - \cos\theta - n + 1\right) = 62\ \mu\text{m},$$

where $n = 1.57$ is the refraction index for the glass of the plates. The expected difference in the optical path, corresponding to the geometrical arrangement of the radiation sources, is defined as

$$\delta_c = 2\left(\tfrac{3}{4}q\lambda + \frac{S}{2}(2\theta_B)^2/2\right) = 64\ \mu\text{m},$$

where $q = 33.5$ is the number of magnetic periods in each undulator, and $S = 4$ m is the distance from M2 to M4. When deriving the expression for δ_c we have taken into account the fact that the radiation beams from the undulators converge in the image plane corresponding to the object plane lying between the undulators (i.e. near the quadrupole L and the magnet M3.

To record the observed interference pictures we used both negative film Micrat and a one-dimensional CCD with a cell size of 20 μm, placed in the image plane RS of the imaging lens ML. The interference pictures shown in fig. 4, were obtained at a conventional (non-achromatic) bend (fig. 4a), at an achromatic bend without delay compensation (fig. 4b), and with the proper compensation (fig. 4c). The experimental optimal delay and the number of the interference bands were as expected. Thus, our experiment confirms the validity of the theoretical considerations [2] on the mutual coherence of spontaneous radiation from two undulators separated by an achromatic bend.

To reproduce "electron beam extraction" from a FEL optical cavity, an external laser can be used to modulate the electron-beam longitudinal density in the first undulator and the laser line shape observed after the achromatic bend in the radiation from the second undulator. Such an experiment is scheduled for the beginning of 1991 on the VEPP-3 storage ring.

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