IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 27, NO. 12, DECEMBER 1991

Observation of Mutual Coherency of Spontaneous Radiation from Two Undulators Separated by Achromatic Bend

N. G. Gavrilov, G. N. Kulipanov, V. N. Litvinenko, I. V. Pinaev, V. M. Popik, I. G. Silvestrov, A. N. Skrinsky, A. S. Sokolov, N. A. Vinokurov, and P. D. Vobly

Abstract—**The mutual coherency of spontaneous radiation from two undulators separated by achromatic bend was observed. Updated magnetic system of optical klystron was implemented for this experiment. The experiments confirm our theoretical expectations. The possible use of the similar technique for efficient power extraction from high-power free-electron lasers (FEL's) is discussed.**

INTRODUCTION

IN 1985 N. Vinokurov proposed "electron beam outcoupling" to solve the problem of mirror damage in high-power FEL's [1]. The proposed apparatus (see Fig. 1) is comprised of an FEL oscillator (1), an achromatic bend (2), and an additional long undulator (3). An electron bunch achieves a density modulation in the FEL oscillator, passes the achromatic bend, and radiates coherently in the additional undulator ("radiator"). In this system, the output power is comparable with the intracavity power.

The preservation of density modulation required for this configuration is equivalent to the coherency of radiation from two undulators separated by a bend, as discussed in [2]. The experiment investigating mutual coherency proves the conservation of electron's correlations in the "electron beam outcoupling" concept, which is planned to be used in a high power IR FEL [3].

MAGNETIC SYSTEM UPDATE

The optical klystron [4] installed on the VEPP-3 storage ring is comprised of two 3.4 m long undulators and a buncher (three pole compensated wiggler) between them. The 0.54 m long drift section between undulators is insufficient to install an achromatic band with a significant deflection angle. We choose a slightly asymmetric lattice for the achromatic bend (see Fig. 2) consisting of three dipoles and one horizontally focusing quadrupole. Therefore, the achromatic bend extends between steering coils M2 and M4 located in the centers of the undulators U1 and U2, respectively. M2 and M4, as well as M3 (see Fig. 3), located in the buncher, are used as the dipoles, and we install a short quadrupole L with a focal length of 3.6 m (at operation energy of 350 MeV). The section of U1 between M1 and M2 is the first undulator and the section of U2 between M3 and M2 is the second undulator. Each undulator is thus $L_u = 1.7$ m long and has 17 periods. The area between M2 and M4, the achromatic bend, is not used as a source of radiation for the experiment. The maximum achromatic deflection angle of $\theta_b = 2$ mrad is limited by the maximum deflection angle, 4 mrad, of M2 and M4. θ_b is three times more than the typical angular divergence of undulator radiation in the red range ($\lambda = 0.63\ \mu$m),

$$\theta_r = (\lambda / L_u)^{1/2} \approx 0.6 \text{ mrad}$$

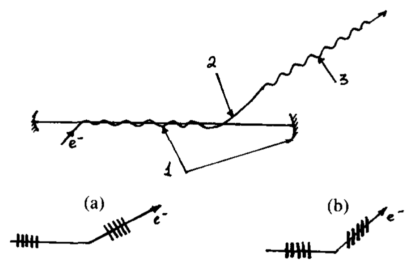

Fig. 1. "Electron beam outcoupling" schematic—1-FEL oscillator; 2-achromatic bend; 3-additional undulator ("radiator"); 4-density modulation after achromatic (a) and simple bends (b).

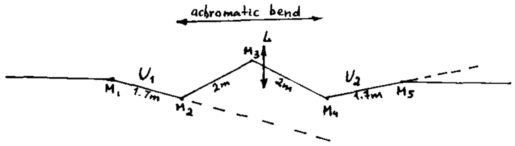

Fig. 2. Schematic of achromatic bend.

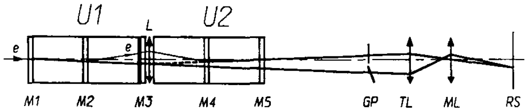

Fig. 3. Layout of magnetic and optical system—M1–M5—steering coils; L—quadrupole lens; U1 and U2—undulators; TL and ML—optical lenses, RS—observation screen, GP-glass plates.

Manuscript received March 22, 1991; revised May 17, 1991.

The authors are with the Institute of Nuclear Physics, 630090 Novosibirsk 90, USSR.

IEEE Log Number 9103659.

0018-9197/91$01.00 © 1991 IEEE

and is sufficient for the experiments. We used the M1 and M5 steering coils to compensate orbit distortion in the storage ring caused by the achromatic bend.

This simple updated system gives us the possibility to have two beams of spontaneous radiation separated by 2 mrad horizontal angle and to control the bend achromaticity by the quadrupole strength.

SYSTEM FOR COHERENCY OBSERVATION

The two coherent sources can provide a spatial interference picture by passing them through an optical system (see Fig. 3) comprised of two optical lenses, TL and ML, with 30× magnification to enlarge the size of interference bands. The screen (or detectors) is located in the plane where radiation from two undulators spatially overlap (i.e., in the imaginary plane of the magnetic system center).

The interference of the spontaneous radiation can be observed when the wave packets radiated by an electron in the two undulators overlap temporally on the entrance of the detector. The length of each wave packet is equal to FEL slippage

$$\Delta = N\lambda = 17 * 0.63\ \mu\text{m} = 10.7\ \mu\text{m}$$

and defines the tolerance for maximum optical path difference. The delay between two wave packets is the sum of delay of the electron versus the wave packet from first undulator and geometrical difference in the path lengths. For our particular geometry and magnetic system an expected delay of 64 μm must be compensated for in order to obtain interference picture.

The time delay was compensated for with the use of two $d = 2.75$ mm thick glass plates (GP on Fig. 3): one was installed on normal incidence angle to the radiation coming from front undulator; the other was tilted for an angle $\theta \approx 20°$ to observe interference. The optical path difference corresponding to this angle

$$\delta = d[(n^2 - \sin^2\theta)^{1/2} - \cos\theta - n + 1] = 62\ \mu\text{m}$$

agrees well with the expected value.

EXPERIMENTAL RESULTS

For interference pictures registration we used negative films (''Micrat'') and a one-dimensional CCD array with 1024 pixels (spaced by 20 μm). The interference bands were observed only in the case when time delay was carefully compensated for and the bend was achromatic [see Fig. 4(c)]. The number of measured interference bands agrees with the expected value of $N_b \sim \theta_b/\theta_r$, where θ_b is the deflection angle and θ_r is the divergence of undulator radiation (see above).

No interference pattern were observed without the time delay compensation [Fig. 4(b)] or without the bend achromaticity [Fig. 4(a)].

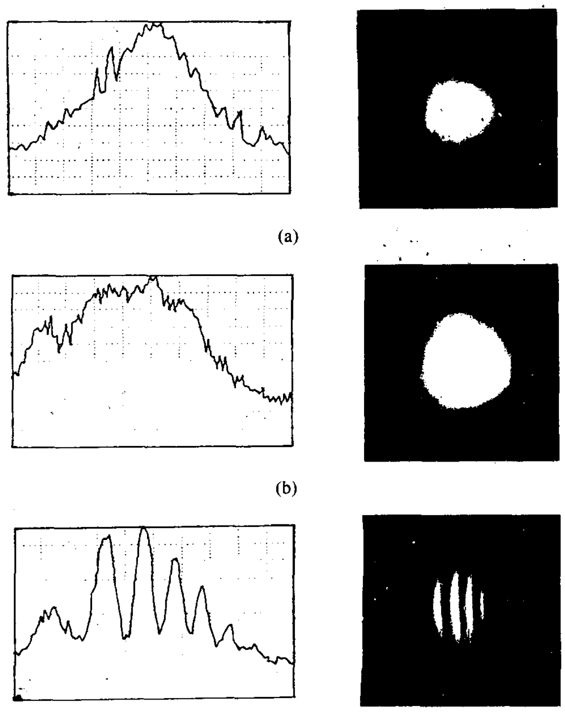
(a)
(b)
(c)

Fig. 4. Interference pictures measured by CCD-array (left-hand side) and photographs (right-hand side). (a) with the conventional bend, but with the time delay compensation; (b) with the achromatic bend, but without the time delay compensation; (c) with the achromatic bend and with the time delay compensation.

CONCLUSION

This experiment confirms our theoretical consideration [2] and shows the importance of bend achromaticity for mutual coherency of spontaneous radiation from two undulators. This schematic can be used to increase area of spatial coherency in X-ray holography based on spontaneous radiation from undulators [2].

This experiments create a strong foundation for future development of ''electron beam outcoupling.'' A possibility of direct imitation of ''electron beam outcoupling'' with the use of an external laser for modulation is under discussion.

REFERENCES

[1] N. A. Vinokurov, *The Electron Beam Outcoupling for High-Power FEL*, unpublished.

[2] G. N. Kulipanov *et al.*, ''On mutual coherency of spontaneous radiation from two undulators separated by achromatic bend,'' *Instit. Nucl. Phys.*, Novosibirsk, USSR, preprint 89-84, 1989.

[3] N. G. Gavrilov *et al.*, ''Project of race-track microtron-recuperator for FEL,'' *Instit. Nucl. Phys.*, Novosibirsk, USSR, preprint 90-82, 1990.

[4] V. N. Litvinenko, ''VEPP-3 storage ring optical klystron: Lasing in the visible and the UV,'' *Instit. Nucl. Phys.*, Novosibirsk, USSR, dissertation, 1989; I. B. Drobyazko *et al.*, *Nucl. Instrum. Methods*, vol. A282, p. 424, 1989.

N. G. Gavrilov, photograph and biography not available at the time of publication.

G. N. Kulipanov, photograph and biography not available at the time of publication.

V. N. Litvinenko, photograph and biography not available at the time of publication.

I. V. Pinaev, photograph and biography not available at the time of publication.

V. M. Popik, photograph and biography not available at the time of publication.

I. G. Silvestrov, photograph and biography not available at the time of publication.

A. N. Skrinsky, photograph and biography not available at the time of publication.

A. S. Sokolov, photograph and biography not available at the time of publication.

N. A. Vinokurov, photograph and biography not available at the time of publication.

P. D. Vobly, photograph and biography not available at the time of publication.