ELECTRON OUTCOUPLING SCHEME FOR THE NOVOSIBIRSK FEL

A.N. Matveenko*, O.A. Shevchenko, V.G. Tcheskidov, N.A. Vinokurov
Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

One of the main problems of contemporary high power FELs is the mirror heating. One of the possible solutions of this problem is the use of electron outcoupling [1, 2]. In this case the mirrors of optical resonator are not transparent and the coherent radiation from an additional undulator in the FEL magnetic system is used. To provide the output of this radiation the electron beam in the auxiliary undulator is deflected from the optical resonator axis. To save bunching it is preferable to use the achromatic deflecting bend. The project of electron outcoupling for the Novosibirsk FEL is described. Simulation results are presented.

INTRODUCTION

The output power of high power oscillator FELs [3] are limited by mirrors heating, leading to surface distortion. Typical gain in oscillator FEL is tens per cent. Correspondingly, optical cavity "quality factor" must be of the order of 10 to make losses lower then amplification. Consequently, intracavity power is at least an order of magnitude higher, than extracted power, and optical cavity mirrors are most loaded compared to mirrors in the user beamlines. Electron outcoupling is one of the possible ways to decrease the power density on the mirrors at the same FEL output power.

The basic idea of electron outcoupling is to output the coherent radiation of the bunched electron beam in the second undulator section (see Fig. 1.), while the bunching is generated in the first section, which is put into optical cavity. In this case the lasing power in the first section can be limited some way (e.g. installing long undulator, or using beam scraper to control cavity losses), but the beam bunching can be preserved. An isochronous bend between the sections brings the beam into the second undulator.

The angle between undulators must be larger then undulator radiation divergence angle $\sim \frac{1}{\gamma}\sqrt{\frac{1+K^2/2}{2N}}$, where N is the number of periods in the undulator, γ is the relativistic factor, K is the planar undulator deflection parameter.

Lengths of the undulator sections are chosen from a condition $\frac{1}{N} \sim 4\pi\frac{\Delta E}{E}$, where ΔE is the r.m.s. energy spread of the electron beam.

Numerical simulations for different electron outcoupling schemes were performed earlier in [4-7]. Here we present design and simulation results for Novosibirsk high power FEL.

*A.N.Matveenko@inp.nsk.su

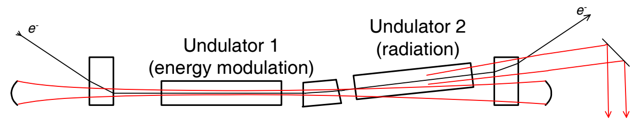

Fig. 1. Electron outcoupling scheme with two undulators and bending section between them. Electron beam path and laser output are shown.

ELECTRON OUTCOUPLING SCHEME OF NOFOSIBIRSK FEL

Electron outcoupling is planned to be used on the 4-th track of the second stage of Novosibirsk FEL. General layout of the second stage is shown in Fig. 2. Main electron beam and laser radiation parameters are summarized in Table 1.

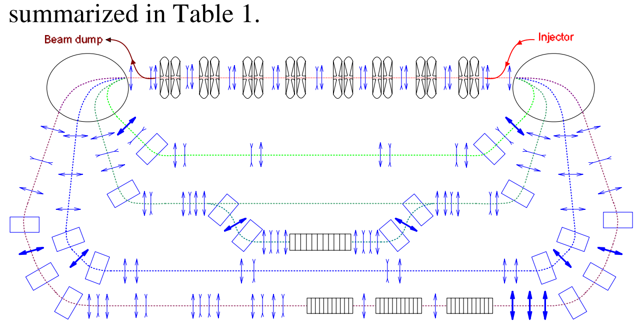

Fig. 2. Layout of the second stage of Novosibirsk FEL.

Table 1. Electron beam and laser radiation parameters.

Energy, MeV	40
Peak current, A	100
Electron beam emittance (normilized), μm	20
Maximum K	2
Undulator period, cm	6
Number of periods in each undulator	28
Deflection angle in second undulator, mrad	3
Relative energy spread	$3\cdot10^{-3}$
Radiation wavelength, μm	15
Optical cavity length, m	40
Mirror radius of curvature, m	25
Mirror reflectivity, %	90
Optical cavity β_x, β_y on mirrors, m	50
Optical cavity β_0 (Raleigh length), m	10

The scheme of the electron outcoupling of Novosibirsk FEL is shown in Fig. 3. It uses three undulators instead of two. The idea lying behind this modification is that in the basic scheme shown in Fig. 1 beam bunching reaches saturation at the end of the first undulator, therefore the efficiency of radiation in the second undulator is reduced. So, if one puts the third undulator (effectively, we divide the first undulator into two) one gets best beam bunching inside the second undulator and better outcoupling efficiency.

Planar permanent magnet undulators are used.

In order to reduce the length of the bends between undulators, we use combined function elements. The achromatic bend between first and second undulators consists of two correctors on the nearest ends of the undulators and a quadrupole shifted off axis to provide both bending and focusing. As the bend is achromatic ($R_{16}= R_{26}=0$), it has also $R_{51}= R_{52}=0$. The last conditions are necessary to tilt electron slices in the bend, saving the bunching, obtained in the first undulator. Bend with shift between second and third undulators is done similarly, though it is not achromatic.

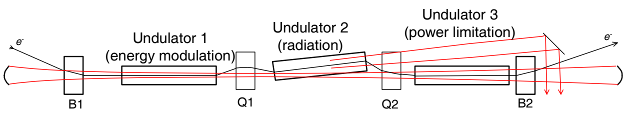

Fig. 3. Electron outcoupling scheme of Novosibirsk FEL. Electron beam path is shown in black. Laser output is shown with red arrows.

Optical functions of the beam in undulators are shown in Fig. 4. All undulators focus in “y” direction with matched β_{y0}=0.529 m at K=2. 4 quads before and 4 after the undulators (see Fig. 2) are necessary to provide appropriate matching to external beamline.

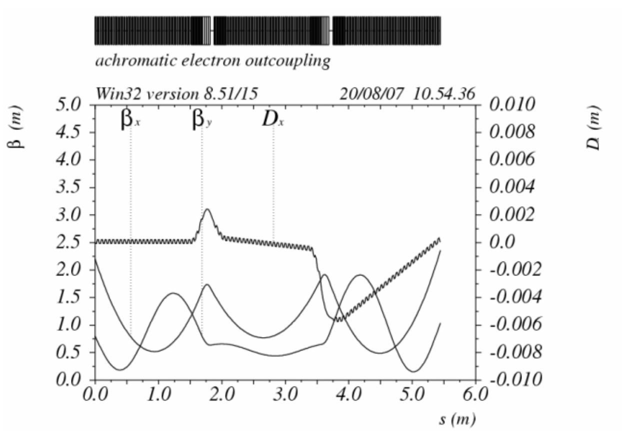

Fig. 4. Optical functions of the beam in undulators.

Optical mode inside the second undulator is partially overlapped with the electron beam, therefore the beam radiates into the mode too. So, simulation of lasing is needed to optimize the outcoupling.

SIMULATION RESULTS

Simulation of electron outcoupling is done with GENESIS [8] and OPC [9] codes. GENESIS is used to simulate the operation of FEL and electron outcoupling itself. OPC is used to propagate radiation field in optical cavity. Beam and optical cavity parameters from Table 1 are used in simulation.

Fig. 5 shows the bunching factor in undulators. The bunching is maximal in the second undulator. GENESIS calculates bunching in axes of the first undulator. The bunching in the second undulator in the axes of second undulator is a little bit higher. (Since the bend between undulators is achromatic, there is no bunching reduction.)

Total (eigenmode and coherent undulator) radiation power growth is shown in Fig. 6.

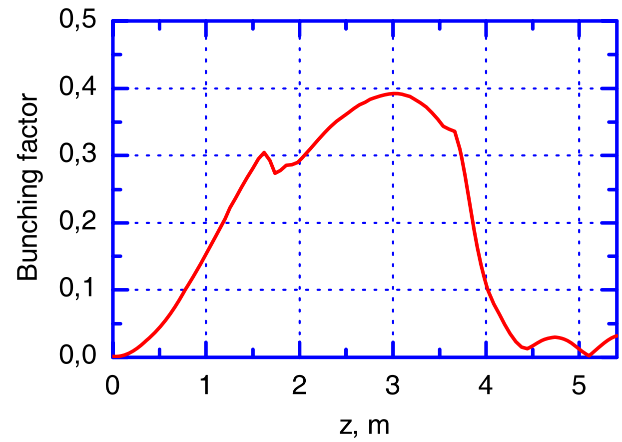

Fig. 5. Bunching factor in undulators.

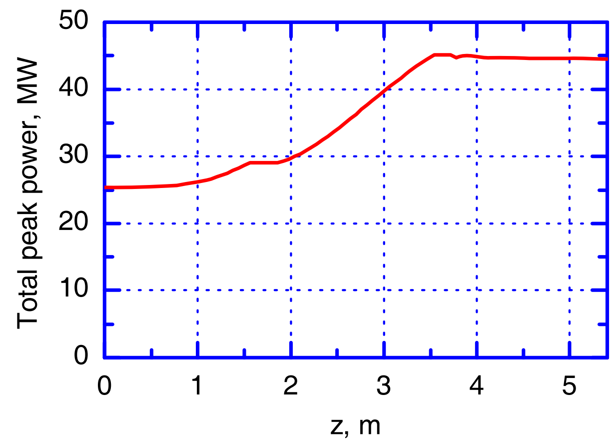

Fig. 6. Total radiation power vs. length.

Figures 7 and 8 demonstrate the power distribution on the optical cavity mirror and on the outcoupling mirror surface (Intensity scales are different for visualisation purposes). Outcoupling mirror is located near the mirror of the optical cavity. Its edge is at the distance of approximately 2.5 cm from the optical axis. The profiles at y=0 are shown in Fig. 9.

Red cross in Fig. 8 shows the expected center of the radiation spot from the second undulator. Circular interference patterns we interpret as interference of radiation from the first and the third undulators. A portion of radiation from the first and the third undulators is also outcoupled. Basic mode in the optical cavity is distorted (it’s center moves off axes) which is seen in Fig. 9.

Total power and intensity on the optical cavity mirrors and outcoupler are listed in Table 2. Given values are for bunch repetition rate 3.75 MHz (which is the optical cavity fundamental frequency) and average current about 6 mA. It is seen that the ratio of the outcoupled power to the intracavity power is more than 25%.

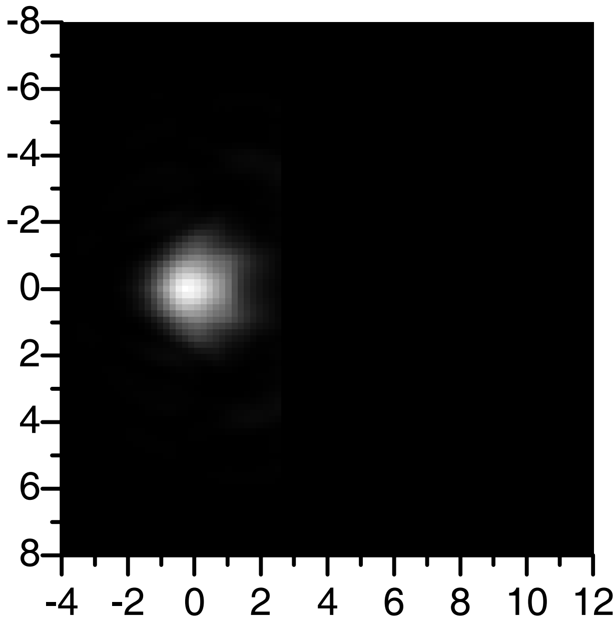

Fig. 7. Power distribution on the forward optical cavity mirror surface. Transverse coordinates are in cm.

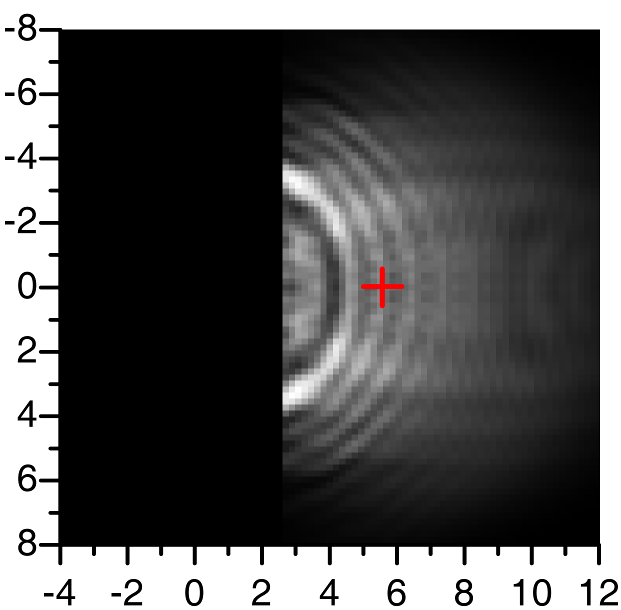

Fig. 8. Power distribution on the outcoupling mirror (scraper) surface. Transverse coordinates are in cm.

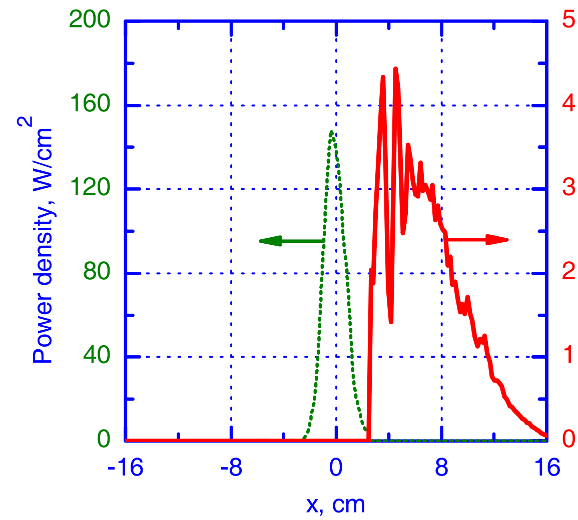

Fig. 9. Intensity profiles: green - on the optical cavity mirror surface, red – on the outcoupling mirror surface. Scales are shown with arrows.

Table 2. Radiation parameters on the forward mirror of the optical cavity and outcoupling mirror.

Total average power on the cavity mirror, W	990
Total outcoupled power, W	260
Max. intensity on the cavity mirror, W/cm^2	170
Max. intensity on the outcoupling mirror, W/cm^2	5

CONCLUSION

In this paper we considered the electron outcoupling scheme with trajectory deflection in the second undulator (radiator). The scheme with deflection in the third undulator was also simulated, but the FEL output power was less for our beam parameters. The results of calculations look reasonable and understandable and show that the chosen parameters of FEL magnetic system are close to optimal.

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