COMPACT RING FEL AS A SOURCE OF HIGH POWER INFRARED RADIATION

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Abstract

Ring FELs [1] were proposed mainly to improve the quality of radiation of x-ray FELs. Their main advantage is the absence of mirrors. It appears that this advantage is also useful for high power FELs. Another reason to build infrared ring FEL is the proof-of-principle for shorter wavelength FELs. Therefore we considered the scheme of infrared ring FEL which requires ERL with beam energy 50 MeV. Using extensive simulations we developed requirements for electron beam parameters and magnetic system of ring FEL. In spite of rather compact design such FEL may provide more than 10 kW average power.

INTRODUCTION

The further development of FELs towards the region of short wavelengths and high powers is limited by the absence of mirrors with appropriate parameters. There exist different approaches to the solution of this problem. One of them is based on the fact that the beam microbunching which appears in undulator can be partly conserved in the specially designed isochronous bend. Electron outcoupling may be considered as the simplest scheme which utilizes this idea [2-3].

The further evolution of this approach leads to the scheme of the ring FEL which has been proposed in [1]. The lattice of the ring FEL consists of straight undulator sections and isochronous bends which compose a ring. At the bends radiation is lost. The signal between adjacent undulator sections is transferred trough microbunching. Radiation from the last undulator produces energy modulation of the new coming beam inside the first undulator and amplification goes on till saturation. The basic advantage of this scheme is that it has a feedback which is realized without any mirrors.

High power ring FEL implies CW operation mode. Therefore one has to use energy recovery linac (ERL) as a source of electron beams for such FEL. The present state of the art of ERLs allows for producing the beams with required parameters which makes the ring FEL project feasible.

The main problem of the ring FEL which becomes very essential for the short wavelength is that it requires isochronous bends to conserve microbunching. The problem of creating of such bend is discussed in detail in [4]. To demonstrate the feasibility of the ring FEL concept it is desirable to build first the small-scale model for longer wavelength which may be interesting itself as a source of high power infrared radiation.

In this paper we consider the possible design of compact high power infrared ring FEL. We present the possible lattice of the bends, required electron beam parameters and results of simulation of FEL operation.

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RING FEL SCHEME AND ELECTRON BEAM PARAMETERS

The schematic layout of the ring FEL is presented in Fig. 1. It includes two undulator sections. One of them plays the role of “modulator” where the energy modulation takes place. The other one may be called “radiator”, here the FEL radiation is generated. In the long wavelength case the debunching of the beam is not very severe problem. Therefore one can use 360 degrees bend and additional undulator sections are not required.

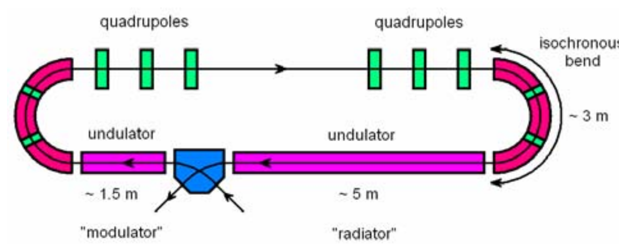

Figure 1. Schematic layout of the ring FEL.

The total 360 degrees bend in the proposed layout is comprised of two 180 degrees isochronous bend sections and a straight section with matching quadrupoles. The lattice of the isochronous bend is presented in Fig 2. It includes three bending magnets with different curvature sign, quadrupoles which are required to focus transversal dispersion and sextupoles which correct the second order aberrations.

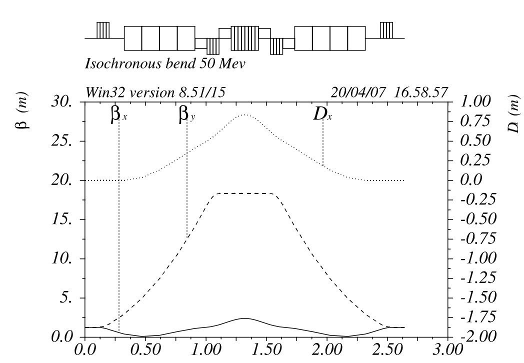

Figure 2. Magnetic lattice of the isochronous bend.

The beam and undulator parameters used in simulations are listed in Table 1.

Table 1: Undulator and electron beam parameters

Undulator period, m	0.06
Undulator deflection parameter	1.5
Electron energy, MeV	50
Beam charge, nC	1
Peak current, A	50/100
Relative r.ms. energy spread, %	0.1
Normalized emittance, mm×mrad	5

The beam parameters presented in this table do not make any problems for contemporary accelerators. In principle one can assume shorter bunch length and higher peak current but in this case the wake field created by coherent synchrotron radiation (CSR) significantly reduces electron efficiency.

PARAMETERS OF OPTIMIZATION AND SIMULATION RESULTS

We used different codes to simulate the ring FEL operation. In this paper we present the results of simulations obtained by the code GENESIS [5] which is widely accepted in the FEL community for simulations of conventional FELs. Strictly speaking it was not pure GENESIS simulation as this code is not adapted for the ring FEL lattice. We used GENESIS to simulate amplification of the FEL signal in the undulator sections. The particle tracking in the bends including second-order aberrations and CSR effects was done by external homemade code.

To obtain the best performance of the FEL first of all we optimized the bend lattice. The purpose of this optimization was to achieve the minimal value of beam debunching factor $\left|1-\left\langle e^{i\omega_0\tau_i}\right\rangle\right|$ (here ω_0 is radiation frequency and τ_i - time delay of the *i*-th electron at the exit from the bend). Adjusting the sextupoles it was possible to make debunching less then 4 %.

The other optimization parameters were the lengths of undulator sections which determine the single-pass gain and saturation power. Length of the last undulator section has to be large enough for the radiation power to reach saturation level, but on the other hand increasing of its length leads to the increase of the gain. It worth noting, that the gain does not have to be too large, otherwise the lasing may become unstable. The gain value can be adjusted either by modulator length or by overlap degree between new-coming beam in modulator and illuminating radiation from radiator.

The optimal beam current is limited by CSR effects. Further we present the simulation results for two cases. In the first case the beam current is assumed to be 50 A and CSR effects are tolerable. In the second case of 100 A current the CSR effects become very significant.

50 A peak current case

Setting of the stationary state in the ring FEL for the considered set of parameters requires approximately 50 passes as it is illustrated in Fig 3. Here one can see the dependence of electron efficiency (which is determined as the ratio of radiation energy to electron bunch energy) on the pass number.

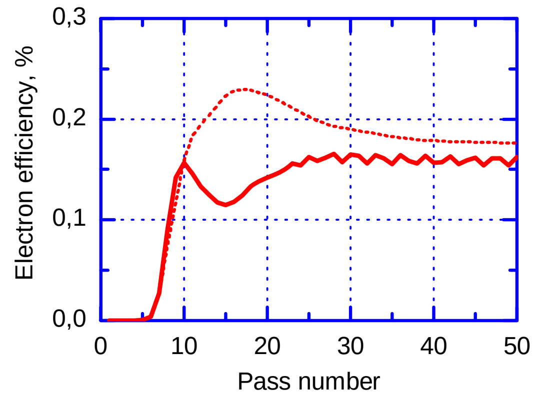

Figure 3. Dependence of the electron efficiency on the pass number in ring FEL for beam current 50 A. Dotted curve corresponds to ideal case without CSR effects.

The dotted curve corresponds to CSR free case. It is seen that CSR effects do not reduce significantly electron efficiency in this case.

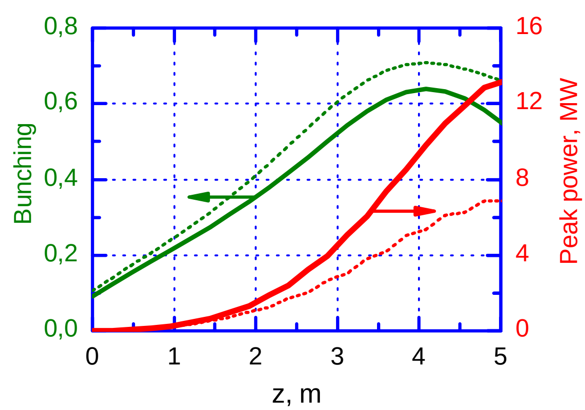

Figure 4. Dependence of the beam bunching factor (green) and peak radiation power (red) on the longitudinal coordinate in the last undulator section (dotted curves – CSR effects are not included).

Dependence of the beam bunching factor and peak radiation power on the longitudinal coordinate in the last undulator section is shown in Fig. 4. Radiation power almost reaches saturation level by the end of undulator (one can probably slightly increase its length yet) and the bunching starts dropping down. It is interesting that the wake created by CSR can increase peak power.

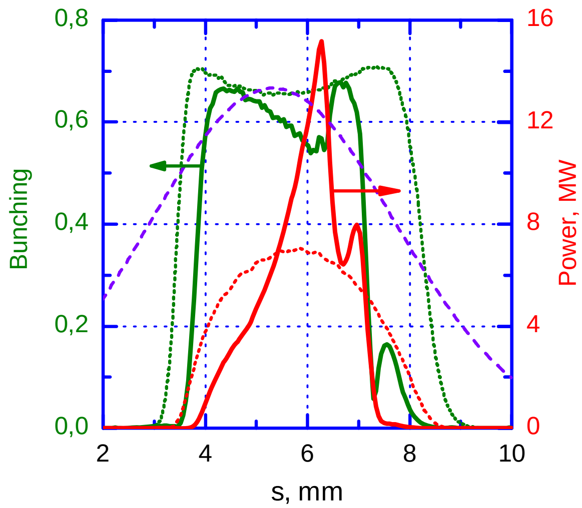

Figure 5. Stationary beam bunching (green) and radiation power (red) distributions at the exit from the last undulator section (dotted curves – CSR effects are not included, dashed violet curve – beam current profile).

The output beam bunching and radiation power distributions corresponding to stationary state are shown in Fig. 5. One can also see here the beam current distribution (dashed violet curve).

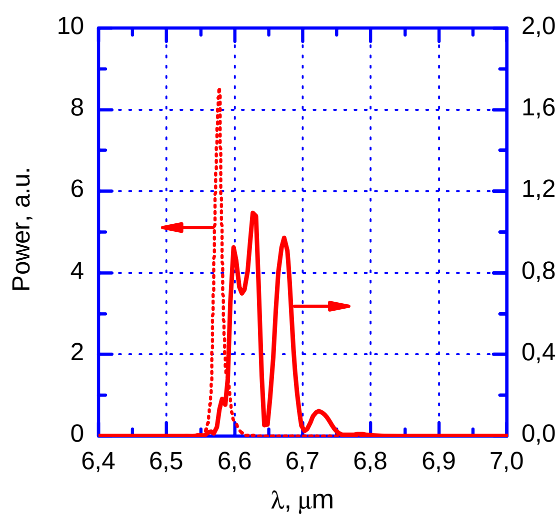

Figure 6. Spectral distribution of the output radiation power (dotted curve – CSR effects are not included).

The output radiation power spectrum is plotted in Fig. 6. From this plot one can see that CSR effects significantly increase the bandwidth.

Table2: Parameters of the output radiation

Wavelength, µm	~ 6.6
Peak power, MW	~ 10
Pulse duration, ps	~ 10
Electron efficiency, %	0.15

Parameters of the output radiation are summarized in Table 2.

100 A peak current case

Increasing the peak current one can increase the radiation peak power but unfortunately in this case the wake field created by CSR effects significantly decreases electron efficiency. This fact is illustrated in Fig. 7-8.

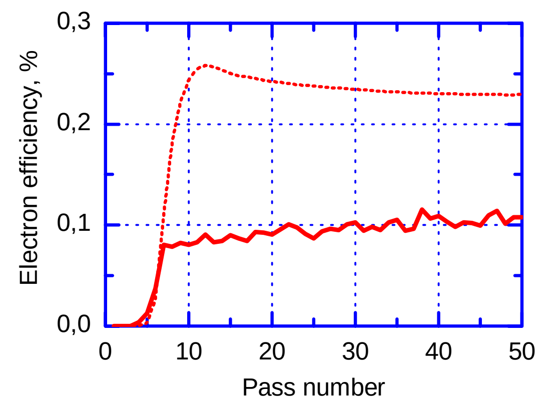

Figure 7. Dependence of the electron efficiency on the pass number in ring FEL for beam current 100 A. Dotted curve corresponds to ideal case without CSR effects.

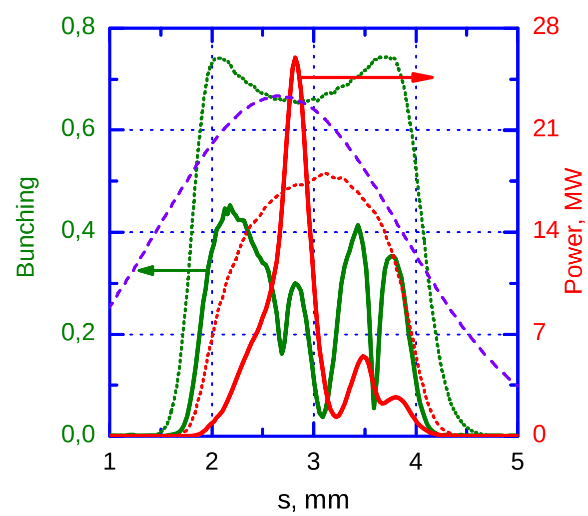

Figure 8. Stationary beam bunching (green) and radiation power (red) distributions at the exit from the last undulator section (dotted curves – CSR effects are not included, dashed violet curve – beam current profile).

One can see from Fig 8. that although the radiation peak power is larger then in CSR free case radiation pulse becomes shorter due to CSR. In this case radiation is formed in the region where the energy chirp created by CSR is small as it is shown in Fig. 9.

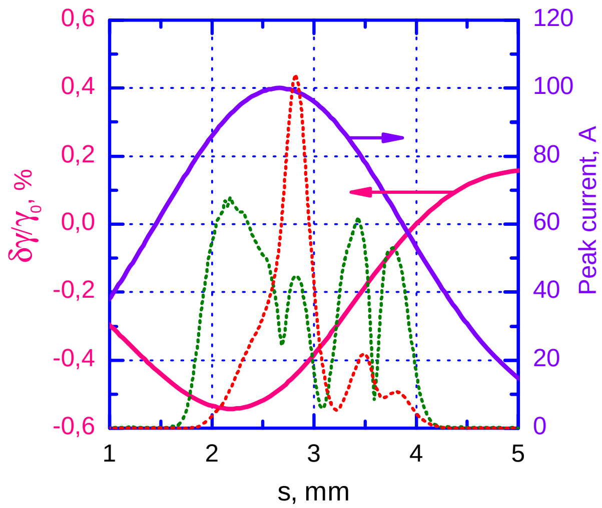

Figure 9. Beam current distribution (violet) and electron energy deviation created by CSR (pink). Dotted curves illustrate the beam bunching (green) and radiation power (red) distributions.

It should be noted that CSR wake field depends on the derivative of the beam current. In our simulations we assumed Gaussian current distribution. In the case of flat-top distribution CSR effects may be smaller.

CONCLUSION

We have shown theoretically the feasibility of the compact high power ring FEL for the infrared region. At that we have considered the problem of beam debunching in the bends and CSR effects. The option to install additional undulator into the free straight section exists. Then all requirements (magnet tolerances, peak current, emittances, etc.) will be even more relaxed. Moreover, the use of this auxiliary undulator may decrease the linewidth.

The next step would be the building of such FEL and demonstrating the feasibility of the ring FEL concept in practice.

REFERENCES

[1] N.A. Vinokurov, O.A. Shevchenko, NIM A528 (2004) 491-496.

[2] N.G.Gavrilov, G.N.Kulipanov, V.N.Litvinenko, I.V.Pinayev, V.M.Popik, I.G.Silvestrov, A.S.Sokolov, P.D.Vobly, and N.A. Vinokurov, IEEE J. Quantum Electron., v.27 (1991), p.2569.

[3] N. A. Vinokurov, NIM A375 (1996) 264.

[4] A.N. Matveenko, O.A. Shevchenko, N.A. Vinokurov, Proc. Of the 2004 FEL Conference, p. 629

[5] S. Reiche, NIM A429, (1999) 243.