Transformation and Adaptation of the Kiloampere Electron Beam Generated in the Linear Induction Accelerator for Pumping a Terahertz FEL

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***Abstract*—The project of a THz free electron laser (FEL) based on a high-current relativistic electron beam is under development at the BINP together with the IAP RAS. In order to drive this FEL it is planned to use the electron beam (energy up to $E_e = 5-10$ MeV, current up to $I_b = 1$ kA, pulse duration up to $\tau_b = 100$ ns, normalized emittance $\sim 550\ \pi \cdot$ mm $\cdot$ mrad) generated at the new linear induction accelerator (LIA). In the framework of previous theoretical work, it was shown that such an electron beam is a suitable driver for an FEL-system based on Bragg reflectors [1]. The proposed FEL scheme allow us to generate coherent pulses of submillimeter radiation in the frequency range of $0.3-1.2$ THz with a sub-gigawatt power level and high energy content (up to ~ 100 J). In the report, we will discuss the main tasks of the project, the methods for their solution and the overall technical project of the FEL.**

***Index Terms*—linear induction accelerator, free electron laser, relativistic electron beam**

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I. Introduction

The project of submillimeter FEL driven by the relativistic electron beam generated at the new linear induction accelerator LIA (energy up to $E_e = 5-10$ MeV, current up to $I_b = 1$ kA) [2], [3] is based on the possibility to create an oversized electrodynamic system with high selectivity [4]. According to our modeling results, such an electrodynamic system can be realized in two ways: a two-mirror resonator with advanced Bragg reflectors ($\varnothing \leq 40\lambda$) or a cavity on the base of Talbot structures ($\varnothing \leq 50\lambda$) [1], [4]. The application of such cavities will provide narrow-band generation with $\Delta\omega/\omega \sim 10^{-4}$ at a high electron efficiency of few percent for the indicated frequency range. To generate sub-mm radiation in such a FEL it is necessary to realize the compression of the beam cross-section from its initial diameter of 40 mm at the LIA exit to the size less than 20λ (20 mm for the radiation frequency of 0.3 THz and 6 mm - for 1 THz) in the case of Bragg reflectors application. Preliminary experiments have shown the possibility of such compression up to the beam diameter of 10 mm [5]. The technical solution of the pulsed magnetic system for such a FEL was developed and optimized based on 3-D modeling results of the beam compression and transport in the FEL electrodynamic system under conditions of a helical undulator magnetic field. In addition, other factors affecting the growth of the beam emittance, limiting the electron efficiency, are discussed [5-7].

II. The design of the FEL magnetic system. Simulations and results

The general scheme of the FEL section connected to the LIA exit, and its main units are described in details in [3], [4]. One of the important tasks for this project implementation is the adaptation of the LIA electron beam for transport in the electrodynamic system of the FEL. It is necessary to note that the main requirement for the design of the FEL magnetic system is the smooth input of the beam from the LIA into the FEL section preserving the beam emittance. This requirement will be met when the ratio of the oscillation amplitude of the compressed beam radius to its average value in the electrodynamic system does not exceed 10 %. The design of the FEL section and its magnetic system that satisfies this requirement is shown in Fig.1.

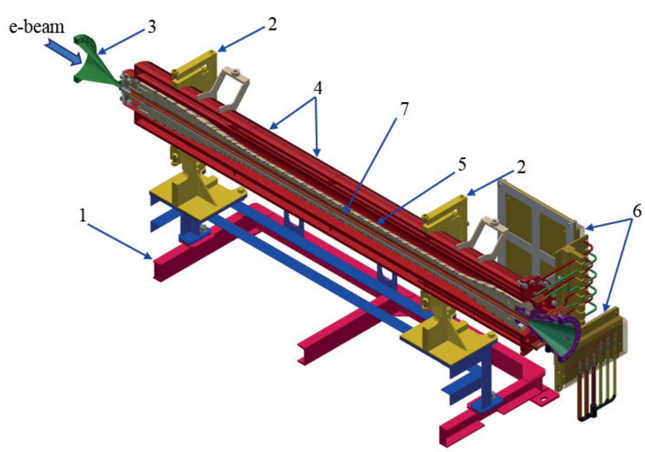

Fig. 1. General scheme of the FEL section. The numbers indicate: 1 - stand, 2 - positioning system of the FEL section, 3 - inlet section of the FEL vacuum chamber, 4 - solenoid of the magnetic compression system (four lenses), located inside the magnetic screen, 5 - helical undulator, 6 - platforms for mounting current supplies from power sources, 7 - FEL electrodynamic system. The blue arrow shows the direction of the electron beam propagation

As it is seen, the beam compression is supposed to be carried out in a region with quasi-homogeneous axially symmetric magnetic field with total length 2 m, produced by four consecutive magnetic lenses supplied with built-in dipole correctors. The field of these lenses together with the lens at the LIA exit according to 3D simulations provide a smooth compression of the electron beam cross section from its initial size of 40 mm to a diameter of 10 mm with the least possible envelope oscillation amplitude not exceeding 1 mm. Also, the magnetic system of the FEL includes undulator formed by four bifilar spiral conductors (see 4 in Fig.1) that produces the helical component of the field to excite the transverse beam oscillations. The chosen geometry of the winding provides a smooth amplitude increase of the electron transverse oscillations along the undulator axis. Fig.2 shows the calculated distribution of the transverse magnetic fields of the helical undulator and longitudinal field of the consecutive magnetic lenses.

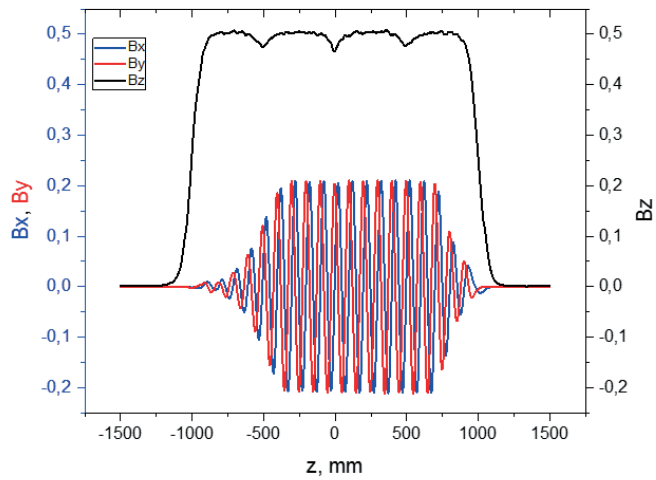

Fig. 2. Distributions of the undulator magnetic field components B_x, B_y and B_z on the magnetic system axis

III. Summary

We have created the computational model to calculate FEL magnetic system and simulate the compression of the beam and its propagation in the magnetic field of the FEL undulator. Based on the simulation results, we have designed the magnetic system for the compression of the e-beam ($E_e = 5 - 10$ MeV, $I_b = 1$ kA) and the buildup of the electron transverse oscillations.

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