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Section A

The project of the high power free electron laser based on the race-track microtron-recuperator

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Abstract

To provide a user facility for the Siberian Centre of Photochemical Researches in Novosibirsk a high power free electron laser is under construction. The project status and installation are described.

1. Introduction

Free electron lasers (FEL) have both advantages (tunability and high average power) and disadvantages (radiation hazard, large size and high cost) in comparison with other types of lasers (see, for example, Refs. [1,2]). One of the prospective goals is the creation of a FEL with an average power of 0.1–1 MW.

During the last years our group developed a project to construct a FEL for operation in the infrared region [3,4]. The main features of this project are: a) the use of the race-track microtron (RTM) that allows energy recovery, as demonstrated earlier [5]; b) an accelerating RF system with a low frequency [6]; and c) the use of so-called "electron output" of light [7,8].

2. The race-track microtron-recuperator

The initial version of the project of the microtron-recuperator was published earlier [3]. Here the updated variant for the FEL facility of the Siberian Centre of Photochemical Researches is described.

The microtron layout and its parameters are shown in Fig. 1 and Table 1. The microtron consists of an injector (1), two magnetic systems of a 180° separating bend (2), a common straight section with RF cavities (3) (the section is meant for electrons with different energies), magnets for the injection (4) and extraction (5) systems, solenoidal magnetic lenses (6), four separated straight sections with magnetic quadrupole lenses (7), a FEL magnetic system (8) placed on the fourth straight section, and a beam dump (9).

The 1 ns electron bunches with a repetition frequency of 45 MHz are produced by the 300 kV electron gun of the injector. The electron bunch is longitudinally compressed in a drift straight section down to 200 ps being modulated in energy at the RF cavity and then accelerated up to 2.1 MeV in the next two RF cavities. Two pairs of identical 65° bending rectangular magnets with alternating signs are used for injection into the common straight section of the microtron. At the exit of the injection system the bunch length is equal to 100 ps.

The distance between the RF cavities in the common straight section is equal to half the wavelength.

The separating bend for the first three tracks of the microtron is a 180° magnetic mirror with two 65° bending magnets on each track. This achromatic magnetic system has horizontal and vertical optical matrices equal to the

Table 1
The microtron-recuperator parameters

RTM RF wavelength	166.3 cm
Number of RTM RF cavities	20
Number of tracks	4
Energy gain per one RF cavity	0.7 MeV
Injection energy	2.1 MeV
Final electron energy	51 MeV
Final electron energy dispersion	0.45%
Final electron micropulses length	20–100 ps
Final peak electron current	20–100 A
Micropulses repetition frequency	2–45 MHz
Average electron current	4–100 mA

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matrix of some empty straight section. The difference in orbit length between subsequent microtron tracks is one wavelength of RF system. The choice of this type of bend and its achromaticity allow us to reduce the horizontal beam size, and to simplify the matching of the β-function on three isolated straight sections containing quadrupole lenses.

To enlarge the available space for the FEL magnetic system a 180° achromatic bend on the fourth track comprises two 90° bends. To further decelerate the electron bunch, the distance between the 90° magnets is such that the length of the fourth track is different from the length of the third track by about $2\frac{1}{2}$ wavelengths of the microtron RF voltage. At the exit from the FEL magnetic system the RF cavity compensates the average losses in electron energy in the FEL. The RF cavity and a detector of the horizontal beam displacement, installed behind a 90° bending magnet, are used for stabilization of the electron energy at the exit of the fourth straight section. Entering again the common straight section from the fourth track, but now in the decelerating phase of the RF system, the electrons release their energy to the RF system. After deceleration down to 2 MeV the electrons are extracted using the magnets of the extraction system (identical to the magnets of the injection system) and are directed to the beam dump.

The mirror symmetry relative to the line going through the centres of the straight sections provides proper focusing of both the accelerated and the decelerated electron beams. The matched β-functions are of the same symmetry.

To maximize the peak electron current (minimize the length of the electron bunch) in the FEL magnetic system, the longitudinal phase motion of the beam in the microtron was optimized by means of small variations in the values of the equilibrium electron energy on each track (and, correspondingly, the microtron geometry) [9]. The equilibrium phases of the four passages through the RF system are $\phi_1 = \phi_2 = 25.3°$, $\phi_3 = 47.2°$, and $\phi_4 = 0°$. We expect that the electron energy dispersion on the fourth track is about 0.45%.

The lengths of the microtron straight sections are chosen so that the accelerated and decelerated bunches (injected at each fourth RF period) are not overlapping on the common track, and hence the mutual influence of the accelerated and decelerated beams at different electron energies drastically decreases.

Calculations of the longitudinal and transverse beam dynamics show that instabilities arise at an average current higher than 0.1 A. The final bunching of the electrons occurs only on the last track with a peak current of about 100 A.

To decrease the beam emittances and energy spread we plan to replace the gridded gun injector by a photoinjector [10,11] which is under development now.

3. The FEL

The magnetic system of the FEL comprises four undulators, two dispersive sections and one achromatic bend. The first three undulators and the two dispersive sections compose the optical klystron used as master oscillator. The number of periods in each undulator is 40, the period length is 9 cm. For easy tuning of the wavelength we use electromagnetic undulators which permit a variation of the deflection parameter K from 1 to 2. By using two dispersive sections, good frequency selectivity is obtained. We should emphasize that this multielement magnetic system of the master oscillator is optimized for having a minimum intracavity light power at reasonable bunching of the electron beam and a small energy spread in the fourth undulator (radiator).

The magnetic system of the achromatic bend is similar to the one discussed and tested earlier [7,8]. Taking into account the angular divergences of the fundamental eigenmode (of the optical resonator) and of the coherent undulator radiation, a deflection angle of 4 mrad was chosen, and the corresponding distance between the axis of the optical resonator and the centre of the beam of coherent radiation near the forward mirror is 14 cm. For the beginning of the operation we choose the simplest optical resonator. Its large length decreases the light intensity on the mirror surface and also makes it possible to obtain oscillations with a low repetition frequency of the electron bunches (less than 2 MHz). Therefore we have a low average

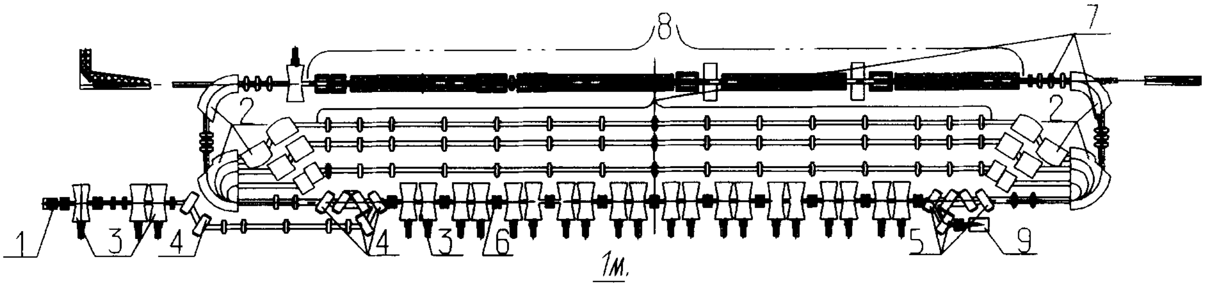

Fig. 1. The layout of the microtron-recuperator.

power and negligible mirrors heating at the regular operating peak power and we can concentrate on careful adjustment of all systems. After that we shall increase the power by increasing the repetition rate of the injector pulses. An estimation of the coherent radiation power from the radiator gives the characteristic resistance value of about few kΩ, so at 100 A peak current we shall have a few tens of MW peak power and at 0.1 A average current we shall have a few tens of kW average power.

The FEL radiation will consist of pulses with a 10–30 ps duration, a 2–45 MHz repetition rate and a 4–13 μm wavelength. By varying the electron energy from one bunch to another with the round-trip period of the optical resonator we can modulate the wavelength.

4. Status and prospects

The mechanical design of the installation will be finished this year; the hardware for the RF generators is manufactured. The existing building for the Siberian Centre of Photochemical Researches is being renovated. The computations and optimization of the FEL are in progress [12–14].

In conclusion we want to point out that the Novosibirsk installation was adapted to meet the demands of the Centre of Photochemical Researches, but nevertheless our approach was developed to provide much higher light power for other applications. Therefore, using the same components (RF generators, accelerating cavities, undulators etc.) and techniques it is possible to create a FEL of the megawatt power diapason.

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