The Project of High Power Free Electron Laser Using Race-Track Microtron-Recuperator

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Abstract

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

1 INTRODUCTION

Free electron lasers (FEL) have both advantages and disadvantages in the competition with another types of lasers (see, for example, [1, 2]). The main advantages are tunability and high average power. The main disadvantages are radiation hazard and large sizes and cost. One of the prospective goals in the FEL technology is the creation of the FEL with average power $0.1\text{—}1MW$.

During the last five years we developed the project of such FEL for operation in the infrared region [3, 4]. The main distinguished features of this project are:
a) the use of energy recovery in the race-track microtron (RTM) demostrated earlier [5];
b) the low frequency accelerating RF system [6];
c) the use of so-called "electron output" of light [7, 8];

2 THE RACE-TRACK MICROTRON-RECUPERATOR

The first version of the project of this accelerator was published earlier [3]. Here we describe the variant updated for the FEL facility for the Siberian Centre of Photochemical Researches.

The layout of the microtron and its parameters are shown at Fig. 1 and Table 1. The microtron comprises an injector 1, two magnetic systems of a 180° separating bend 2, a common straight section with RF cavities 3 (the section is common to the electrons of 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 300 kV electron gun of the injector produces 1 ns electron bunches with repetition frequency of 45 MHz. After passing through the RF cavity modulating the electron energy the bunch is longitudinally compressed in a drift straight section down to 200 ps and then accelerated up to 2.1 MeV in the next two RF cavities. The electrons are injected into the common straight section of the microtron using two pairs identical 65° bending rectangular magnets with alternating signes. The bunch length is equal to 100 ps at the exit of the injection system.

Table 1: The Microtron-Recuperator Parameters

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

The RF cavities in the common straight section are distant from each other at the half of 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 magnetic system is achromatic, and its horizontal and vertical optical matrices are equal to the matrix of some empty straight section. The difference in the orbit length between the subsequent microtron tracks is one wavelength of RF system. The choice of this type of bend and its achromaticity allows to the electron bunches with different energies to pass through RF cavities of the common straight section, to reduce the horizontal beam size, and to simplify the matching of β-function on three isolated straight sections containing quadrupole lenses.

To enlarge available space for the FEL magnetics system a 180° achromatic bend on the fourth track comprises two 90° bends. The distance between 90° magnets are such that the length of the fourth track is different from the length of the third track by about $2\frac{1}{2}$ of the wavelength of the microtron RF voltage. At the exit from the FEL magnetic system there is the RF cavity to compensate the average losses in electron energy in the FEL. The RF cavities and a detector of horizontal beam displacement, installed behind a 90° bending magnet stabilize 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 RF system,the electrons release its energy to the RF system during the passage in the same direction through the same three microtron tracks. After that the electrons are extracted using the magnets of the extraction system (identical to the mag-

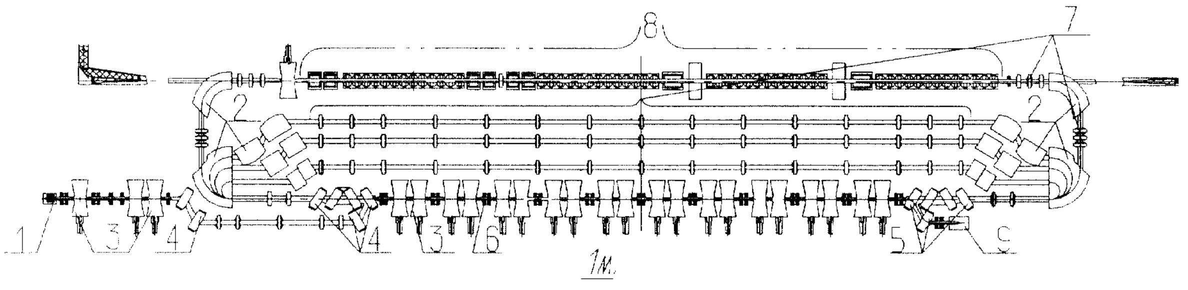

Figure 1: The layout of the microtron

nets of the injection system) and are directed to the beam dump.

To provide the proper focusing of both the accelerated and the decelerated electron bunches the magnetic system (except for the fourth track) is mirror-symmetrical relative to the line going through the centres of the straight sections. Here the matched β-functions are of the same symmetry.

To minimize the length of the electron bunch (to maximize peak electron current) 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 four passages through the RF system are $\phi_1 = \phi_2 = 25.3°$, $\phi_3 = 47.2°$, and $\phi_4 = 0.6°$. Electron energy dispersion on the fourth track is 0.45%.

The lengths of the straight sections of the microtron are such that with the injection of one electron bunch in each four periods of its RF voltage (i.e. at $45MHz$ frequency), on the common track the accelerated and decelerated bunches are not overlapping. In this case, a mutual influence of the accelerated and decelerated beams at different electron energies is drastically decreases.

Calculations of the longitudinal and transverse beam dynamics show that the microtron-recuperator can operate in the steady mode at an average current higher than $0.1A$. Here the final bunching of electrons occurs only on the last track, thereby contributing to the obtaining of the high (about $100A$) peak current, and small transverse emittances of the beam being conserved.

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

3 THE FEL

The magnetic system of FEL consists of four undulators, two dispersive section and one achromatic bend. First three undulators and two dispersive sections compose the optical klystron using as master oscillator. Optical resonator consists of two mirrors and have a 79 *m* length. The number of periods in each undulator is 40, the period length - 9 *cm*. For easy tuning of wavelength we use electromagnetic undulators which permit to vary the deflection parameter K from 1 to 2. The reason of the use of two dispersive section is obtaining of a good frequency selectivity. To see this, let us remind that in conventional optical klystron there are many maxima of gain which corresponds to condition $s = (n - \frac{1}{4})\lambda$, ($\lambda$ - wavelength, n - any integer, s - the lag of electron passing from the centre of first undulator to the centre of second one from light). For the case of two dispersion sections we ought to satisfy two such conditions for the wavelength simultaneously (for different s_1 and s_2) and so the maxima will occur more rare. Such a configuration of magnetic system provide not only fine but also fast tuning of the wavelength, because it's easy to change the field in dispersion sections with a high speed. It needs to emphasize that this multielement magnetic system of the master oscillator is optimized for having minimum of intracavity light power at reasonable bunching of electron beam and small energy spread in the fourth undulator (radiator).

The magnetic system of achromatic bend is similar to that discussed and tested previously [7, 8]. Taking into account the angular divergences of the fundamental eigenmode (of the optical resonator) and of the coherent undulator radiation we choose the 4 milliradians deflection angle. Therefore corresponding distance between the axis of optical resonator and the centre of coherent radiation beam near the forward mirror is 14 *cm*. For the beginning of operation we choose the simplest optical resonator. Its big length decrease the light intensity on the mirror surface but also make possible to obtain oscillations with low repetition frequency of the electron bunches (less than 2 MHz). Therefore we'll have low average power (and so negligible mirrors heating) at the regular operating peak power and can concentrate on the careful adjustment of all systems. After that we may increase the power by the increase of the repetition rate of the injector pulses. For example, at repetition rate $45MHz$ it'll increase 24 times and at $180MHz$ - 96 times. The estimation of the coherent radiation power from the radiation gives the value of its characteristic resistance about few kW. Then at the

100A peak current we are to have few tens of MW peak power and at 0.1A average current - few tens of kW average power.

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

4 STATUS AND PROSPECTS

The mechanical design of installation is to be finished this year. The hardware for the RF generators is manufactured. The existing building for the Siberian centre of Photochemical Researches is under updating. The facility will be available for users in 1996.

The computations and optimization of FEL are in progress now [12, 13, 14].

In the conclusion we are to point out that the Novosibirsk installation was adapted to meet the demands of the centre of Photochemical Researches. But our approach was developed to provide much higher light power for another applications. Therefore using the same components (RF generators, accelerating cavities, undulators etc.) and techniques it's possible to create FEL of the megawatt power diapason.

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