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Abstract

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

1. Introduction

During the last five years at the Budker Institute of Nuclear Physics a project of powerful IR CW FEL was developed [1,2]. The main features of this project are the use of the race-track microtron (RTM) that allowed energy recovery, demonstrated earlier [3], the low frequency accelerating RF system [4], the use of electron outcoupling [5,6]. The FEL will be capable to produce 10-100 kW of CW power in the 6.5-13 μm region.

2. The Race-track Microtron-Recuperator

The initial version of the project of the microtron-recuperator was published earlier [1]. Here the variant updated for the FEL facility of the Siberian Center of Photochemical Researches is described.

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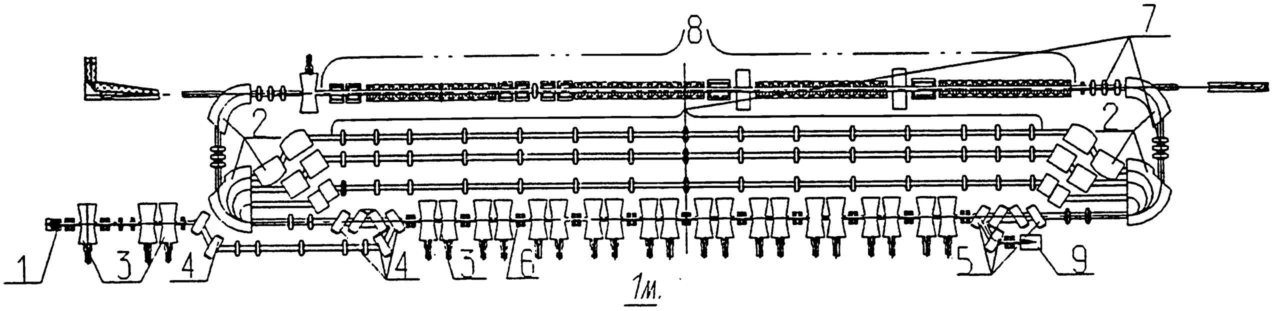

Fig. 1. The layout of the microtron-recuperator:
1 - injector; 1.1 - electron gun of the injector, 1.2 - bunching straight section, 2 - magnets of the 180° separating bend, 3 - RF cavities, 4 - magnets of the injection system, 5 - magnets of the extraction system, 6 - solenoid magnetic lenses, 7 - quadrupole magnetic lenses, 8 - magnetic system of the FEL, 9 - beam dump.

The microtron layout and its parameters are shown in the Fig. 1 and the 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 common to the electrons with different energies), magnets for the injection 4 and extraction 5 systems, solenoid magnetic lenses 6, four separated straight sections with the magnetic quadrupole lenses 7, a FEL magnetic system 8 placed on the fourth straight section, and a beam dump 9.

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

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

The distance between RF cavities in the common straight section is equal to the half of the wavelength. The solenoid focusing on this section is chosen aiming to provide proper focusing of electron bunches with various energies.

Table 1

Racetrack Microtron 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 psec
Final peak electron current	20-100 A
Micropulses repetition frequency	2-45 MHz
Average electron current	4-100 mA

The separating bend for the first three tracks of the microtron comprises a 180° magnetic mirror and two 65° bending magnets on each track. This achromatic magnetic system has horizontal and vertical optical matrices equivalent 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 allows us to reduce the horizontal beam size, and to simplify the matching of ß-function on three isolated straight sections containing quadrupole lenses.

To enlarge space available for the FEL magnetic system an achromatic bend on the fourth track consists of two 90° bends. To obtain deceleration of the electron bunch after passing through the FEL distance between 90° magnets is such that the fourth track is longer than the third track by about $2^1/_2$ of the wavelength of the microtron RF voltage. At the exit from the FEL magnetic system the RF cavity compensates the average losses in the electron energy in the FEL. This RF cavity and a detector of 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, 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 centers of the straight sections provides the proper focusing of both the accelerated and the decelerated electron beams. The matched ß-functions are of the same symmetry.

To maximize peak electron current in the FEL magnetic system (i.e. minimize length of the electron bunch) 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) [7]. We expect the electron energy dispersion on the fourth track less than 0.45%.

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

2. The FEL

The FEL magnetic system comprises four identical undulators, two magnetic dispersive sections and one achromatic bend. The parameters of the FEL magnetic system are shown in Table 2. First three undulators and two dispersive sections compose the optical klystron using as master oscillator. For easy tuning for desirable wavelength we use electromagnetic undulators which will permit us to vary the undulator parameter K from 1 to 2. Using two dispersive sections will allow us to obtain good frequency selectivity and to have the minimum of intracavity light power at reasonable bunching of electron beam and the small energy spread in the fourth undulator (radiator).

The magnetic system of achromatic bend is similar to the discussed and tested previously [5,6]. Taking into account the angular divergence of the fundamental eigenmode (of the optical resonator) and of the coherent undulator radiation the 4 milliradians deflection angle was chosen, and the corresponding distance between the axis of the optical resonator and the center of coherent radiation beam near the forward mirror is 14 cm. The magnetic system of this achromatic bend includes a single horizontal focusing (F=2 m) quadrupole of 9 cm in a full magnetic length and 6 cm in an aperture diameter, which is centered between two identical couples of parallel edges magnets. Each couple of the magnets will have 15 cm of a full magnetic length, 4 cm of a gap and 2.5 kGs of a magnetic field, so we will have 0.8 cm of horizontal dispersive function in the quadrupole. Its total longitudinal dispersion will be about Nd=50.

Table 2

The FEL Magnetic System Parameters

Undulator period	9 cm
Undulator parameter, K	1-2
Number of periods in undulator	40
Dispersive section magnetic length	36 cm
Maximal magnetic field	3 kGs
Maximal dispersion, Nd	80
Gap	4 cm

The symmetrical optical cavity of the master FEL has 79.2 m of length and about 40 m of mirrors curvature radii. Its large length decreases the light intensity on the mirror surface and also makes it possible to obtain the oscillations with low repetition frequency of the electron bunches (less than 2 MHz). Therefore we'll have low average power and negligible mirrors heating at the regular operating peak power and can concentrate on the careful adjustment of all systems. After that we shall increase the power by the increase of the repetition rate of the injector pulses. The estimation of the coherent radiation power from the radiator gives that at the 100 A peak current we shall have a few tens of MW peak power and at 0.1 A average current - a few tens of kW average power.

The FEL radiation will consist of pulses with a 10-30 psec duration, 2-45 MHz repetition rate and 6.5-13 μm wavelength. Varying the electron energy from one bunch to another with the round-trip period of the optical resonator we can modulate the wavelength.

3. Injection System

At present by the stuff of the Institute of Chemical Kinetics and Combustion the thermionic injector is produced and is being tested. To decrease the beam emittances and energy spread we plan to change the gridded gun injector by the photoinjector [8] which is under development now. The photoinjector with DC power supply will have better vacuum conditions (and longer photocathode lifetime), less energy spread of the electron bunch, and no emittance degradation specific to the RF guns [9].

At first stage the microtron-recuperator will be supplied by the abovementioned thermionic gun and the experiments with the photoinjector will be carried out separately. The aim of these experiments will be improving of a photocathode preparation technology, a possibility of a simple fabrication and/or change of the photocathode, investigating the electron beam parameters, quantum efficiency, and photocathode lifetime.

The photoinjector comprises an entrance chamber, a photocathode preparation chamber, two manipulators, a DC high voltage power source, a photogun, and an illuminating laser (see the Fig. 2).

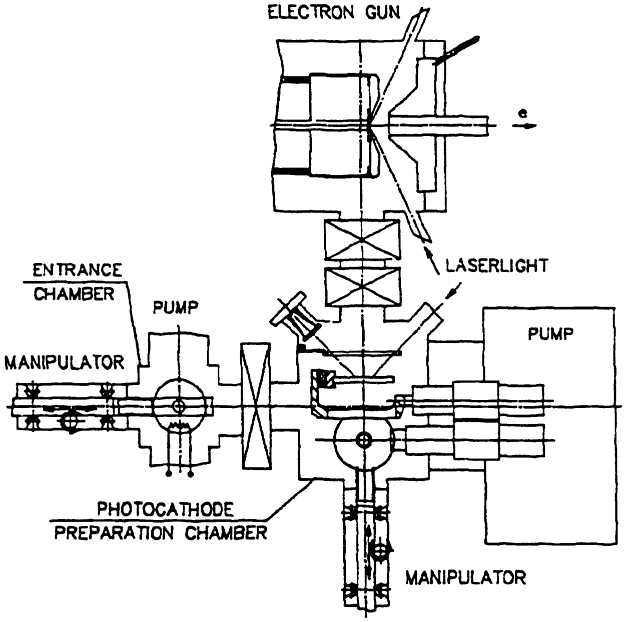

Fig. 2. The photoinjector layout.

The photocathode holder being loaded into the entrance chamber is preliminary baked for outgassing. A vacuum valve closing the entrance chamber from the main vacuum volume prevents the contamination of the high vacuum volume. After outgassing the first manipulator transfers the holder to the photocathode preparation chamber. To avoid contamination of the photogun during the photocathode activation the photogun vacuum volume is separated from the cathode preparation chamber by a vacuum valve. The second manipulator transfers the holder inside photocathode preparation chamber as well as to the photogun.

The diode type photogun has a photocathode active area of 0.5 cm^2. To improve vacuum conditions the anode is cooled with liquid nitrogen. The photocathode is illuminated by the argon laser at 70° incidence angle. The high voltage power source developed at the Budker INP for use in industrial accelerators `Malutka' is capable to produce 300 kV voltage at 100 mA current.

The photocathode preparation chamber is divided in two sections: the photocathode surface is finally cleaned in the first one and is activated in the second. During the fabrication process the photocathode is illuminated by the laser light through the quartz window, and the quantum yield will be estimated from the current of the collector.

The argon illuminating laser produced by the Institute of Automatics and Electrometry (Novosibirsk) has an average power 10-15 W at 458 nm wavelength. The active mode-locking should provide less then 200 psec pulse duration at the 45 MHz repetition frequency. The power supply of the illuminating laser is performed by a modified commercial DC source capable to produce current up to 500 A and voltage up to 600 V and has system for the arc discharge suppressing.

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 Center of Photochemical Researches is under updating. The computations and optimization of FEL are in progress now [10,11].

At present the manipulators, the entrance and photocathode preparation chambers, the illuminating laser have been manufactured and will be assembled in the near future. The Fig. 3 shows the photocathode preparation chamber and ready for assembling high voltage insulator.

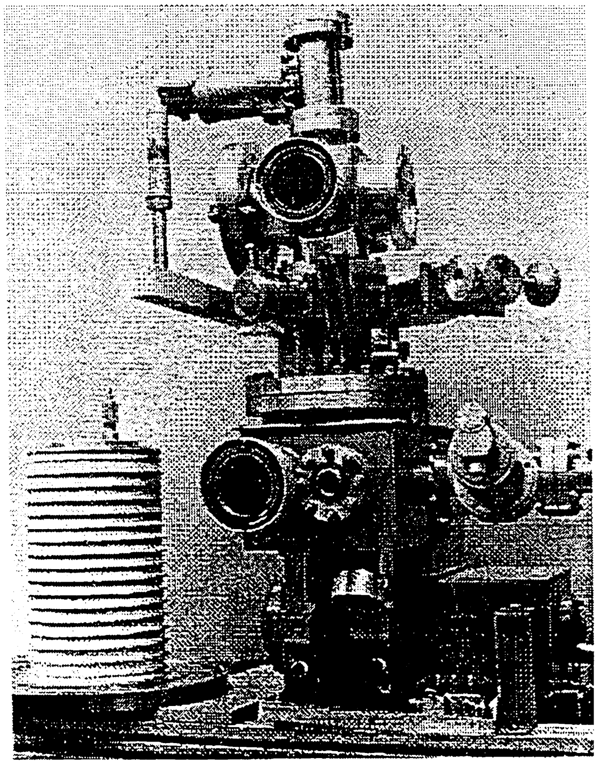

Fig. 3. The photocathode preparation chamber and high voltage insulator.

In conclusion we want to point out that the Novosibirsk installation was adapted to meet the demands of the Center 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 FEL of the megawatt power diapason.

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