Status of the Novosibirsk high-power free-electron laser project

N. Gavrilov, E. Gorniker, D. Kayran, G. Kulipanov, I. Kuptsov, et al.

N. G. Gavrilov, E. I. Gorniker, D. A. Kayran, G. N. Kulipanov, I. V. Kuptsov, G. Ya. Kurkin, E. I. Kolobanov, Yu. I. Levashov, A. D. Oreshkov, S. P. Petrov, V. M. Petrov, Igor V. Pinayev, V. M. Popik, T. V. Salikova, I. K. Sedlyarov, T. V. Shaftan, A. N. Skrinsky, Nikolai A. Vinokurov, P. D. Vobly, E. M. Zakutov, "Status of the Novosibirsk high-power free-electron laser project," Proc. SPIE 2988, Free-Electron Laser Challenges, (15 May 1997); doi: 10.1117/12.274381

Event: Photonics West '97, 1997, San Jose, CA, United States

Status of the Novosibirsk high power free electron laser project

N. G. Gavrilov, E. I. Gorniker, D. A. Kayran, G. N. Kulipanov, I. V. Kuptsov, G. Ya. Kurkin, E. I. Kolobanov, Yu. I. Levashov, A. D. Oreshkov, S. P. Petrov, V. M. Petrov, I. V. Pinayev, V. M. Popik, T. V. Salikova, I. K. Sedlyarov, T. V. Shaftan, A. N. Skrinsky, N. A. Vinokurov, P. D. Vobly, and E. M. Zakutov

Budker Institute of Nuclear Physics
Lavrentyev Prospect 11, 630090, Novosibirsk, Russia

ABSTRACT

A free electron laser with high average power is under construction in the Siberian Scientific Center. Purpose of this project is to provide the Siberian Center of Photochemical Research with a user facility. The project status and features are described in this paper.

Keywords: free electron lasers, accelerators

INTRODUCTION

The tunability and potentially high average power make free electron lasers (FELs) very attractive for many scientific and technological applications. The Novosibirsk project is aimed to provide the source of few-kilowatt infrared radiation for the Siberian Center of Photochemical Research. The FEL itself will be a prototype for more powerful FELs.

The most distinguished features of our approach to the high power FEL design are following.

- The energy recovery. As the typical for the FELs efficiency of the energy transfer from the electron beam to radiation is of order of one percent, the recovery of the used beam energy is extremely useful, reducing dramatically the radiation hazard and increasing the net efficiency "from plug".
- The low-frequency RF system. The relatively low (180 MHz) frequency provides possibility to use separate accelerating cavities with independent tuning of modes and relatively inexpensive tetrode generators. It is also very preferable from the point of view of the beam dynamics.
- The "electron output" of light, which is simply the use of the coherent undulator radiation. The FEL-oscillator is necessary to bunch the electron beam at the entrance of undulator-radiator.

To meet better the future user requirements the significant modification of the magnetic system was made last year. The number of orbits was increased to 8, instead of 4 in the previous design.[1, 2]

THE ACCELERATOR - RECUPERATOR

The accelerator-recuperator layout is shown in Fig. 1. The 2 MeV electron beam from the injector passes 8 times through the accelerating structure, getting the 98 MeV energy, and comes to the FEL, installed in the last straight section. After the loss of about 1% of its power the beam passes through the accelerating structure 8 times more. The length of the last orbit is chosen to provide deceleration at these 8 passes, therefore the beam returns the power to the accelerating structure and comes to the beam dump with almost the injection energy.

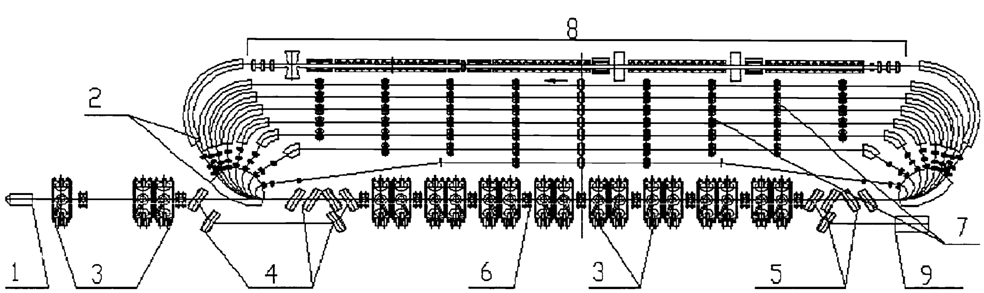


Fig. 1. The accelerator-recuperator layout. 1 - 300 keV electron gun; 2 - bending magnets; 3 - RF resonators; 4, 5 - injection and extraction magnets; 6 - focusing solenoids; 7 - straight sections with quadrupoles; 8 - the FEL magnetic system; 9 - the beam dump.

Some parameters of the accelerator are listed in the table:

RF wavelength, m	1.6614
Number of RF cavities	16
Amplitude of accelerating voltage at one cavity, MV	0.8
Number of orbits	8
Injection energy, MeV	2
Final electron energy, MeV	98
Bunch repetition frequency, MHz	2 - 22.5
Average current, mA	4 - 50
Final electron energy dispersion, %	0.2
Final electron bunch length, ps	20 - 100
Final peak electron current, A	100 - 20 .

The 300 keV electron gun of the injector produces the 1 ns electron bunches with a repetition frequency up to 22.5 MHz. It have the DC power supply (rectifier) and thermionic cathode with the greed. After passing the modulating RF cavity the electron bunch is compressed in a drift section down to 200 ps and accelerated up to 2 MeV in the next two RF cavities. After that electrons are injected into the common straight section of the microtron- recuperator using two pairs of the identical bending magnets with opposite magnetic field signs. At the entrance to the main accelerating system the bunch length is 100 ps. The 300 keV photoinjector was developed[3] to replace the thermionic gun in future.

The accelerating structure consists of 16 RF cavities. Each cavity have mechanical tunings for the fundamental and high order modes. The effective accelerating voltage is 0.8 MV at the thermal power consumption about 0.1 MW. So the total RF power is near 2 MW. The details of the RF system design and tests were described in paper.[4]

The orbit geometry was chosen to meet the following conditions:

- the length of all orbits (except of the eighth one) are equal to integer numbers of the RF wavelength;
- the distances between straight sections are equal;
- each 180 - degree bend is achromatic.

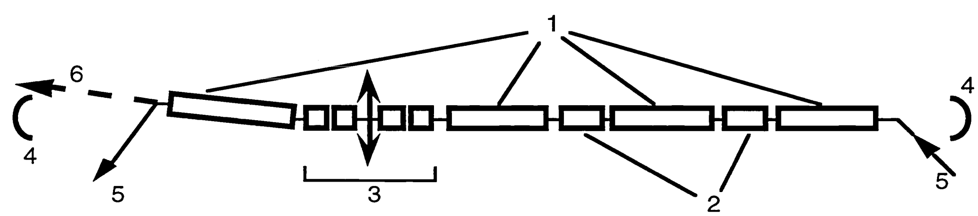
First condition is necessary for synchronous acceleration.[5] The eighth orbit is longer, than the seventh one by 1.45 of the RF wavelength to obtain deceleration at the next eight passes through the RF structure. The second make the design more compact. The third condition eliminates coupling of horizontal betatron and longitudinal motions and makes focusing more flexible. The splitting magnets are round and the field value in all magnets is the same. The quadrupoles into the 180-degree bends makes each of these bends achromatic. The quadrupoles at the long straight sections are optimized to focus properly both accelerating and decelerating beams.

The length of the straight sections was chosen such, that, when the electron bunches are injected at the every eighth period of the RF voltage (e.g. with a frequency of 22.5 MHz), the bunches under acceleration and deceleration are not overlapping each other on the common track, but fill all available equilibrium phases homogeneously. In this case the interaction of the electron bunches, having various energies decreases dramatically.

Computer simulations of the longitudinal and transverse beam dynamics show, that the microtron- recuperator is capable to operate with an average current above 0.1 A. The final bunching occurs on the last track and that allows to achieve a high peak current (about 100 A) without significant emittance degradation.

THE FEL MAGNETIC SYSTEM

The magnetic system of the FEL consists of four undulators, two bunchers (dispersive sections), and one achromatic bend (see Fig. 2).



Fig, 2. The layout of the FEL magnetic system. 1 - undulators; 2 - dispersive sections; 3 - achromatic bend; 4 - mirrors; 5 - electron beam; 6 - output coherent radiation.

The first three undulators and the dispersive sections compose the optical klystron using as a master oscillator. The optical resonator of about 79m length consists of two mirrors. The number of periods in each undulator is 36, length of the period is 9 cm. To simplify the wavelength tuning we use electromagnetic undulators with the maximum of deflection parameter K about 2. The reason for using of two dispersive sections is to improve the frequency selectivity. To make it clear, consider the two-undulator optical klystron. Let s is the delay of an electron, passing from the middle of the first undulator to the middle of the second one, with respect to the wavefront of light, propagating between these two points (s is also the delay between the wavetrains, emitted by an electron in undulators). The maximum amplification takes place at the wavelengths λ, which satisfy the condition $s = (n - 1/4)\lambda$, where n is the integer. If there are two bunchers and three undulators, we must satisfy two similar conditions simultaneously (for two different s_1 and s_2) to obtain the maximum. Therefore the maxima will occur more rarely. Such a configuration offers fine and fast wavelength tuning and flexibility. The parameters of this FEL-oscillator are chosen to minimize the intra-cavity power and the energy spread increase at the fourth undulator (radiator) and to maximize the electron density modulation (bunching) at the fourth undulator.

The magnetic system of the achromatic bend consists of four bending magnets and focusing quadrupole lens. The detail consideration and results of tests of such achromatic bend are described in papers[6,7]. Taking into account the angular divergence of the fundamental eigenmode of the optical resonator and of the coherent undulator radiation we chose the 4 mrad deflection angle. The distance between the center of the mirror and the coherent radiation axis is 14 cm. The fourth undulator (radiator) is the same, as the previous three, but with slightly lower field amplitude (it is easy, as the undulators are electromagnetic) to maximize the output power[8].

For the initial operation we choose the simplest optical resonator. Its large length decreases the light intensity on the mirror surfaces and makes possible to obtain oscillation with a low (2 MHz) repetition frequency of the electron bunches. Therefore we will have a low average power (and therefore negligible heating of the mirrors), while the peak power will be high. After that we will be able to increase the average power, increasing the repetition rate of the injector pulses.

The FEL radiation will consist of pulses with 10-30 ps duration, 2-22.5 MHz repetition rate, and 1-10 μm wavelength.

THE CURRENT STATUS

The building update is finished now. The electron gun was installed and commissioned last year. The assembly of the RF generators and manufacturing of the RF cavities are in progress.

REFERENCES

1. N. G. Gavrilov et al., IEEE J. Quantum Electron., QE-27, pp. 2626-2628, 1991.
2. N. A. Vinokurov et al., Nucl. Instr. and Meth. A 375, pp. 403- 406, 1996.
3. N. G. Gavrilov et al., Nucl. Instr. and Meth., A331, pp. ABS17-ABS18, 1993.
4. V. S. Arbuzov et al., Proc. 1993 Particle Accelerator Conf. PAC 93, v. 2, pp. 1226-1228.
5. R. E. Rand, *Rercirculating Electron Accelerators*, Harwood Academic Publishers, 1984.
6. G. N. Kulipanov et al., IEEE J. Quantum Electron., QE-27, pp. 2566-2568, 1991.
7. N. G. Gavrilov et al., IEEE J. Quantum Electron., QE-27, pp. 2569-2571, 1991.
8. G. N. Kulipanov et al., Nucl. Instr. and Meth. A375, pp. 576 - 579, 1996.