ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2006, Vol. 3, Suppl. 1, pp. S40–S42. © Pleiades Publishing, Inc., 2006.

A Project of Accelerator–Recuperator for Novosibirsk High-Power FEL[1]

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Abstract—The first stage of the Novosibirsk high-power free-electron laser (FEL) was commissioned in 2003. It is driven by a CW energy recovery linac. The next step will be the full-scale machine, a four-track accelerator–recuperator based on the same RF accelerating structure. This upgrade will permit to get shorter wavelengths in the infrared region and increase the average power of the FEL by several times. The scheme and some technical details of the project are set out. The installation will be a prototype for future multiturn accelerator–recuperators.

PACS numbers: 29.17.+w; 41.60.Cr, 29.27.Eg

DOI: 10.1134/S1547477106070107

INTRODUCTION

A new source of terahertz radiation was commissioned recently in Novosibirsk [1]. It is a CW free electron laser (FEL) based on an accelerator–recuperator (AR), or an energy recovery linac (ERL). It differs from the earlier ERL-based FELs [2, 3] in the low-frequency non-superconducting RF cavities and longer wavelength operation range. The full-scale Novosibirsk free electron laser is to be based on the four-track 40 MeV AR (see Fig. 1). It is to generate radiation in the range 3–80 μm [4, 5].

1. INJECTOR

The electron source is a 300 keV DC gun with a gridded cathode. The electron gun consists of:

• a cathode-grid unit driven by a controlled pulser;

• an electrostatic accelerating tube placed in a high-pressure vessel with insulating SF_6 gas;

• a 300 kV DC power supply;

• control electronics inside the high-voltage terminal with the optical link.

Basic parameters of the gun are:

Electron energy (kinetic) 300 keV

Current:

peak 1.7 A

average 40 mA

Normalized emittance 20 π mm mrad

Repetition rate 0–22.5 MHz

Pulse duration 1.1 ns

Operation mode CW

The gridded cathode of the commercial RF tube is used as the source of short electron bunches. The home-made pulser provides 1.5 ns 100 V pulses at the cathode (the grid is grounded). As such pulse (bunch) duration is too long for the RF acceleration at a frequency of 180 MHz, bunch compression is necessary. The simplest way to do it, klystron bunching at the same frequency, was chosen. The gun voltage of 300 kV is a trade-off between suppression of the space charge induced emittance degradation and the possibility to compress the bunch in the drift space with no magnetic

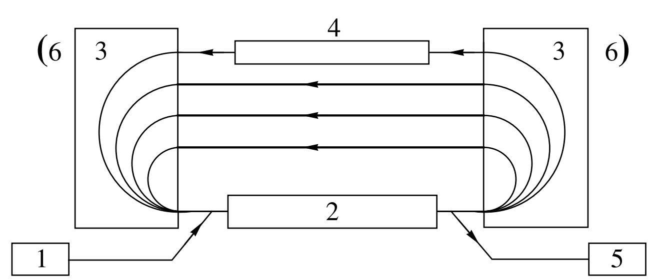

Fig. 1. Scheme of the accelerator-recuperator based FEL. 1—Injector, 2—accelerating RF structure, 3—180° bends, 4—undulator, 5—beam dump, 6—mirrors of the optical resonator.

[1]The text was submitted by the authors in English.

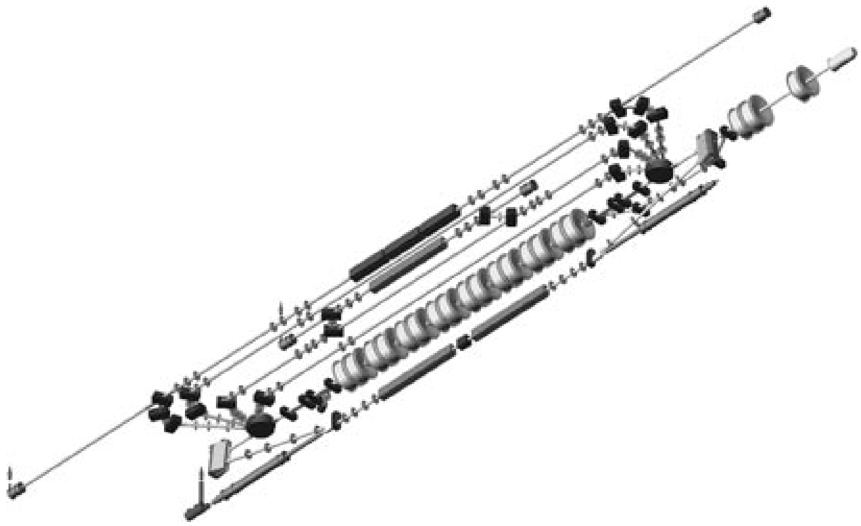

Fig. 2. Layout of both accelerators-recuperators (bottom view).

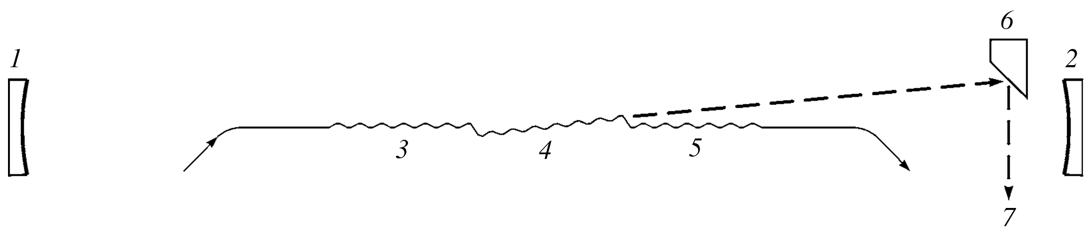

Fig. 3. Scheme of the electron outcoupling for the second stage of the Novosibirsk FEL. *1* and *2*—mirrors of optical resonator; *3*, *4*, and *5*—undulators; *6*—45° mirror; *7*—radiation output.

buncher. The RF voltage on the bunching cavity is about 100 kV. After the 2.5 m drift space, two accelerating cavities are installed. They increase the beam energy to 1.7 MeV and compensate the correlated energy spread gained in the bunching cavity.

2. ACCELERATOR-RECUPERATOR

The full-scale AR is based on the same accelerating structure as the first-stage one, contains four tracks, and is arranged horizontally (see Fig. 2). The distinctive feature of the RF-structure is comparably low frequency, 180 MHz. It permits to increase the bunch charge and/or improve the beam quality. As the first-stage machine is placed in the vertical plane, both accelerators will exist simultaneously. One of them can be chosen by switching the bending magnets. Basic expected parameters of the full-scale AR are:

Electron beam energy, 40 MeV

Number of orbits 4

Maximum bunch repetition rate, 90 MHz

Beam average current, 150 mA

Rms energy spread, relative 2×10^{-3}

Rms longitudinal spread, 2.6 ps

After significant upgrade of the injector 150 mA average current will be available.

The machine contains injection magnets, extraction ones, two sets of achromatic bends, and a bypass in the second track for an additional FEL. Each set contains a separation round magnet and a number of rectangular dipole magnets. The dispersion in the bents was chosen so as to provide $\pi/2$ rotation in the longitudinal phase space from the injection point to the middle of the second track and additional π to the middle of the last one. So the bunches are much shorter in the second track and in the last one than in the injection point, and the peak current in both FELs is increased significantly.

3. FEL

Two FELs will be installed on the machine: in the final track with the energy 40 MeV and in the second one with the energy 20 MeV. The first FEL will generate up to 10 kW in the 3–20 μm region, while the second one more than 1 kW in the 40–80 μm. As the output power of the first FEL is great enough, an electron outcoupling scheme [6] is used (see Fig. 3). The correlated energy spread is gained in the first undulator under the action of the wave in the optical resonator. The beam is then microbunched in the undulator and the shift. The second undulator causes coherent emission of the microbunched beam at some angle to the resonator axis. Finally, the exhaust beam (still partially microbunched) is returned to the axis and radiates some power to the resonator to maintain auto-oscillation. The intra-resonator power in this case is significantly lower than in the standard FEL scheme.

CONCLUSIONS

Designing and manufacturing of the full-scale, four-track AR is underway. The commissioning is planned in a few years. The FELs installed in the AR will dramatically widen the wavelength range and increase the power of the existing Novosibirsk FEL. Moreover, the machine will be a prototype for future multiturn ARs [7].

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