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Status of the Novosibirsk terahertz FEL ☆

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Abstract

The first stage of Novosibirsk high-power free-electron laser (FEL) was commissioned in 2003. It is based on the normal conducting CW energy recovery linac. Now the FEL provides electromagnetic radiation in the wavelength range 120–180 μm. The average power is 200 W. The minimum measured line width is 0.3%, which is close to the Fourier-transform limit. The assembly of user beamline is in progress. Plans of future developments are discussed.

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Keyword: Free-electron laser

1. Introduction

A new source of terahertz radiation was commissioned recently in Novosibirsk [1]. It is the CW free-electron laser (FEL) based on an accelerator–recuperator, 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. Full-scale Novosibirsk free-electron laser is to be based on the four-orbit 50 MeV electron accelerator–recuperator (see Fig. 1). It is to generate radiation in the range from 3 μm to 0.2 mm [4,5].

2. Accelerator–recuperator

The first stage of the machine contains a full-scale RF system, but has only one orbit. The

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layout of the accelerator–recuperator is shown in Fig. 2. The 2 MeV electron beam from an injector passes through the accelerating structure, acquiring 12 MeV energy, and comes to the FEL, installed in the straight section. After interaction with radiation in the FEL, the beam passes once more through the accelerating structure, returning the power, and comes to the beam dump at the injection energy. Main parameters of the accelerator are listed in Table 1.

The electron source is the 300 keV DC gun with gridded cathode. Recently, we changed the cathode-grid unit to the new one, and the charge per bunch increased to 1.5 nC.

3. FEL

The FEL is installed in a long straight section of a single-orbit accelerator–recuperator. It consists of two undulators, a magnetic buncher, two mirrors of the optical resonator, and an outcoupling system. Both electromagnetic planar undulators are identical. The length of an undulator is 4 m, period is 120 mm, gap is 80 mm, and deflection parameter K is up to 1.2. One can use one or both undulators with or without a magnetic buncher. The buncher is simply a three-pole electromagnetic wiggler. It is necessary to optimize the relative phasing of undulators and it is used now at low longitudinal dispersion $N_d < 1$.

Both laser resonator mirrors are identical, spherical, of 15 m curvature radius, made of gold-plated copper, and water-cooled. In the center of each mirror, there is a hole. It serves for mirror alignment (using the He–Ne laser beam) and output of a small amount of radiation. The distance between mirrors is 26.6 m. The forward mirror has hole with diameter 3.5 mm, and the rear mirror has one with diameter 8 mm. The calculated transparency of the mirror with the 8-mm hole, at the wavelength 150 μm, is 1.5%. At this wavelength, the measured round-trip loss is near 7%. The output radiation passes through two windows, which separates the FEL and accelerator vacuum from the atmosphere. After the forward mirror, the additional iris and the normal-incidence quartz

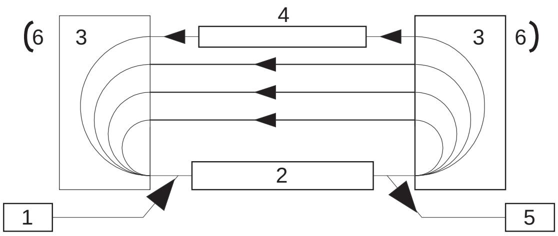

Fig. 1. Scheme of the accelerator–recuperator-based FEL. (1) Injector, (2) accelerating RF structure, (3) 180-degree bends, (4) undulator, (5) beam dump, and (6) mirrors of the optical resonator.

Table 1
Accelerator parameters (first stage)

RF frequency (MHz)	180
Number of RF cavities	16
Amplitude of accelerating voltage at one cavity (MV)	0.7
Injection energy (MeV)	2
Final electron energy (MeV)	12
Maximum bunch repetition rate (MHz)	22.5
Maximum average current (mA)	20
Beam emittance (mm mrad)	2
Final electron energy spread, FWHM (%)	0.2
Final electron bunch length (ns)	0.1
Final peak electron current (A)	10

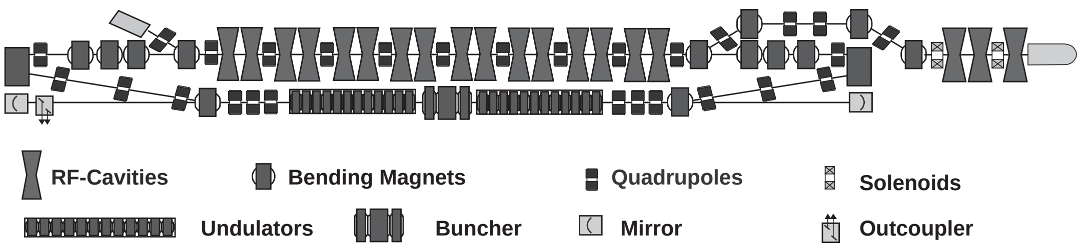

Fig. 2. Scheme of the first stage of the Novosibirsk high-power FEL.

mirror are installed. After the rear one, there is a diamond window, tilted at the Brewster angle.

For FEL operation, we used both undulators. Beam average current was typically 8 mA at the repetition rate 5.6 MHz, which is the round-trip frequency of the optical resonator and 32nd subharmonics of the RF frequency $f_0 \approx 180$ MHz.

4. Radiation study

The first measurements of radiation parameters were reported before [1]. Instead of the fine tuning of the optical resonator length, we tuned the RF frequency. The tuning curve is shown in Fig. 3. The preliminary simulation results [6] demonstrate a reasonable agreement with measured data.

The average radiation power, passed through the hole at the rear mirror, was about 200 W. Taking into account the 7% loss, one gets approximately 1 kW of power, extracted from the electron beam. The electron beam power was 100 kW. Therefore, electron efficiency is about 1%. The typical radiation parameters are listed in Table 2.

To demonstrate the capabilities of our terahertz radiation source, we made a hole in a plexiglas (PMMA) cube (see Fig. 4). Using a short-focusing mirror, the CW breakdown in air was achieved (see Fig. 5).

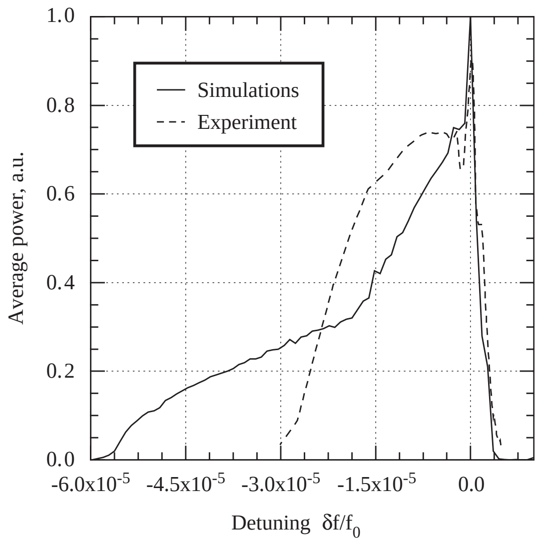

Fig. 3. Dependence of the average power on the RF frequency detuning.

Table 2
Radiation parameters

Wavelength (mm)	0.12…0.18
Minimum relative line width, FWHM	0.003
Pulse length, FWHM (ns)	0.05
Peak power (MW)	0.6
Repetition rate (MHz)	5.6
Average power (kW)	0.2

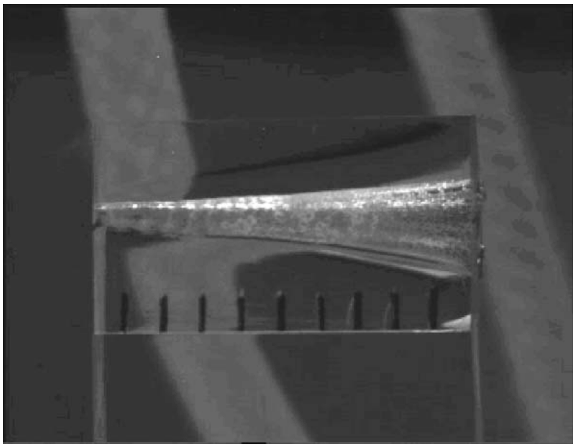

Fig. 4. The conic hole in the PMMA cube, done with the terahertz radiation ablation. One division is 5 mm.

To transmit the radiation from the rear mirror hole to user stations, the beamline from the accelerator hall to the user hall was built. It comprises one spherical mirror and 5 flat mirrors inside stainless steel tubes. Now the beamline is filled by nitrogen. It is separated from the accelerator vacuum by the diamond window, and from the air by the polyethylene window. The beamline was commissioned successfully, and some preliminary optical measurements and experiments were done.

5. Further developments

We plan to increase further the output power. Factor two may be obtained by the increase of the

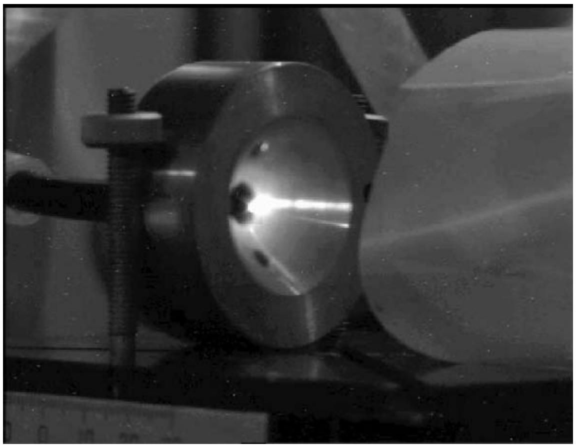

Fig. 5. The CW discharge in the focus of the parabolic mirror.

diameter of the hole in the rear mirror. The electron gun upgrade for the increase of the average current up to 0.1 A is under consideration.

As we have the two-section undulator, further attempts to increase the FEL efficiency by the proper tapering looks promising.

The mechanical design of the second stage of the FEL is in progress.

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