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 micron. The average power is 200 W. The minimum measured linewidth 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.

INTRODUCTION

A new source of terahertz radiation was commissioned recently in Novosibirsk. [1]. It is CW 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 micrometer to 0.2 mm [4, 5].

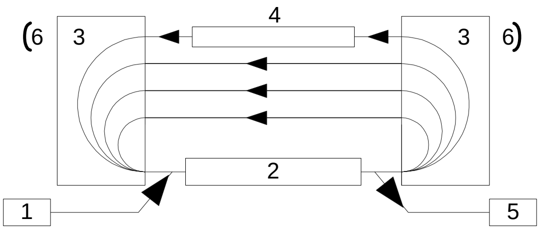

Figure 1: Scheme of the accelerator-recuperator based FEL. 1 - injector, 2 - accelerating RF structure, 3 - 180-degree bends, 4 – undulator, 5 – beam dump, 6 – mirrors of the optical resonator.

ACCELERATOR-RECUPERATOR

The first stage of the machine contains a full-scale RF system, but has only one orbit. Layout of the accelerator–recuperator is shown in Fig. 2. The 2 MeV electron beam from an injector passes through the accelerating structure, acquiring the 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.

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 emitance, mm·mrad	2
Final electron energy spread, FWHM, %	0.2
Final electron bunch length, ns	0.1
Final peak electron current, A	10

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.

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, the 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 is used now at low longitudinal dispersion $N_d < 1$.

Both laser resonator mirrors are identical, spherical, 15 m curvature radius, made of the 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 small amount of radiation. The distance between mirrors is 26.6 m. The forward mirror

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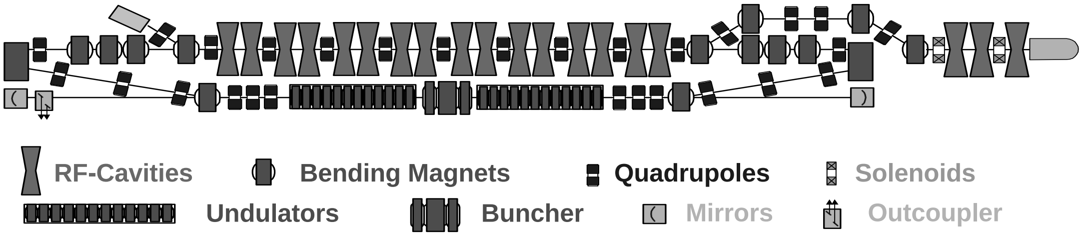

Figure 2: Scheme of the first stage of the Novosibirsk high power FEL.

has the hole with the diameter 3.5 mm, and the rear one - with the diameter 8 mm. The calculated transparency of the mirror with the 8-mm hole, at the wavelength 150 micron, is 1.5%. At this wavelength the measured round-trip loss are near 7%. The output radiation pass through two windows, which separated the FEL and accelerator vacuum from the atmosphere. After the forward mirror the additional iris and the normal-incidence quartz 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 32-th subharmonics of the RF frequency $f_0 \approx 180$ MHz.

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.

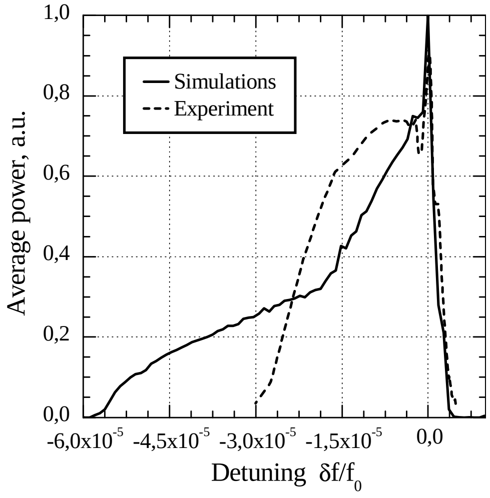

Figure 3: Dependence of the average power on the RF frequency detuning.

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

Table 2: The radiation parameters

Wavelength, mm	0.12...0.18
Minimum relative linewidth, FWHM	0.003
Pulse length, FWHM, ns	0.05
Peak power, MW	0.6
Repetition rate, MHz	5.6
Average power, kW	0.2

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

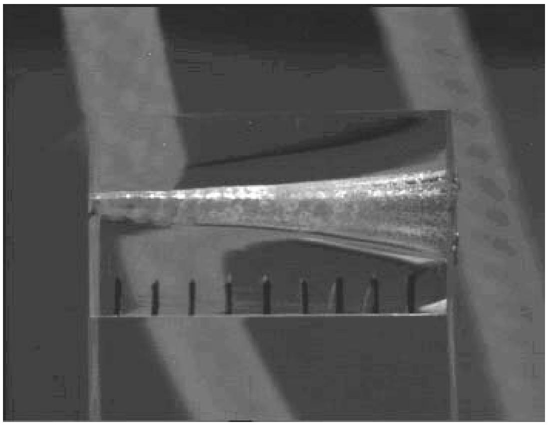
Figure 4: The conic hole in the PMMA cube, done with the terahertz radiation ablation. One division is 5 mm.

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 of one spherical mirror and 5 flat mirrors inside the 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.

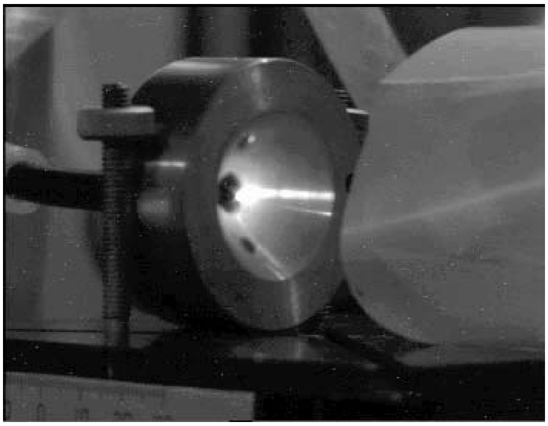

Figure 5: The CW discharge in the focus of the parabolic mirror.

FURTHER DEVELOPMENTS

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