STATUS OF THE NOVOSIBIRSK HIGH POWER TERAHERTZ FEL*

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Abstract

The first stage of Novosibirsk high power free electron laser (FEL) has been commissioned in 2003. It is based on the normal conducting CW energy recovery linac (ERL). Now the FEL provides electromagnetic radiation in the wavelength range 120 - 230 micron. The maximum average power is 400 W. The minimum measured linewidth is 0.3%, which is close to the Fourier-transform limit. Four user stations are in operation now. Manufacturing of the second stage of the FEL based on a four-track energy recovery accelerator is in progress.

INTRODUCTION

A new source of terahertz radiation was commissioned a few years ago in Novosibirsk [1]. It is a CW FEL based on a ERL. Its differences from other ERL-based FELs [2, 3] are: a low frequency non-superconducting RF system and longer wavelength operation range. A full-scale Novosibirsk FEL will be based on the four-track 40 MeV energy recovery accelerator (see Fig. 1). It will generate radiation in the range from 5 micrometer to 0.24 mm [4, 5] together with the first-stage FEL.

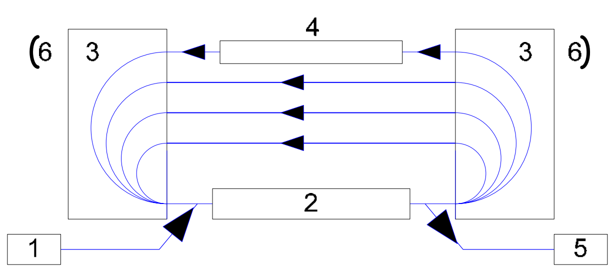

Figure 1: Scheme of an energy recovery accelerator based FEL. 1 - injector, 2 - accelerating RF structure, 3 - 180-degree bends, 4 – undulator, 5 – beam dump, 6 – mirrors of the optical resonator.

ACCELERATOR-RECUPERATOR

The first stage machine contains a full-scale RF system, but has only one track. The scheme of the ERL is shown in Fig. 2. A 2 MeV electron beam from an injector passes through the accelerating structure, gains 12 MeV energy there, and comes to an FEL, installed in the straight section. After interaction with radiation in the FEL the beam passes once more through the accelerating structure, returns the power, and comes to a beam dump at the injection energy. Main parameters of the accelerator are listed in Table 1. The electron source is a 300 keV DC gun with a gridded cathode. Maximum charge per bunch is 1.7 nC.

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

FEL

The FEL is installed in a long straight section of the backward track of the ERL. It consists of two undulators, a magnetic buncher, and an optical resonator. Both electromagnetic planar undulators are identical: the length is 4 m, the period is 120 mm, the gap is 80 mm, and the deflection parameter *K* is up to 1.2. The buncher is 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 spherical, of 15 m curvature radius, made of gold-plated copper, and water-cooled [6]. There is a hole in the centre of each mirror. It is intended for mirror alignment (using the He-Ne laser beam) and output of small amount of radiation. The distance between the mirrors is 26.6 m. The forward mirror has the hole of the diameter 3.5 mm, while the rear one of 8 mm (see Fig.3). The calculated transparency of the 8-mm hole mirror is 1.5% at the wavelength 150 μm. The measured round-trip loss is near 7% at this wavelength. The output radiation passes through two windows which separate the FEL vacuum system from the atmosphere. An additional iris and a normal-incidence quartz window are installed after the forward mirror. A diamond window tilted at the Brewster angle is used for outcoupling behind the rear mirror.

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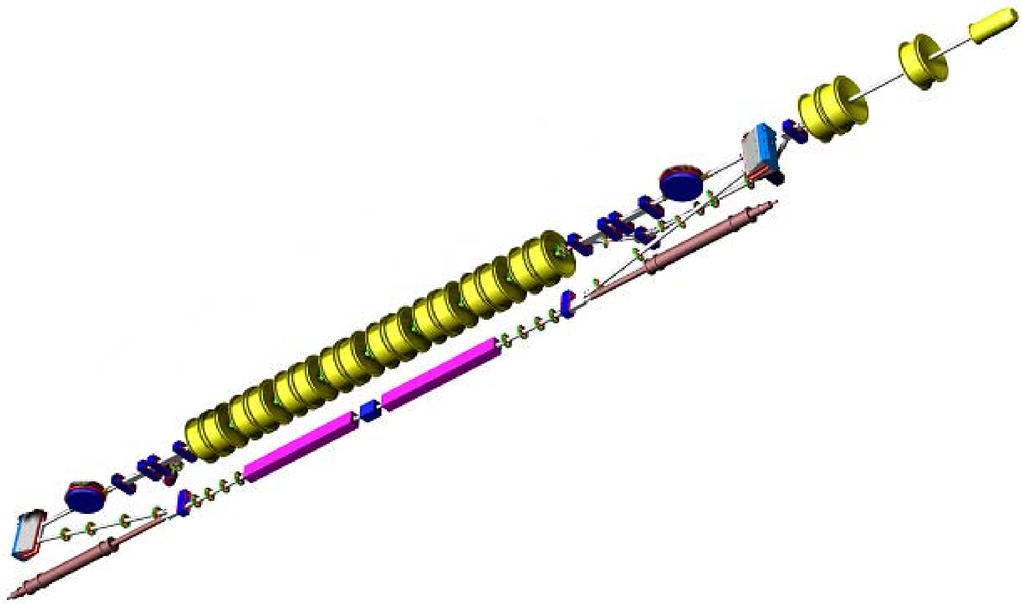

Figure 2: Scheme of the first stage of the Novosibirsk terahertz FEL. The loop lies in the vertical plain.

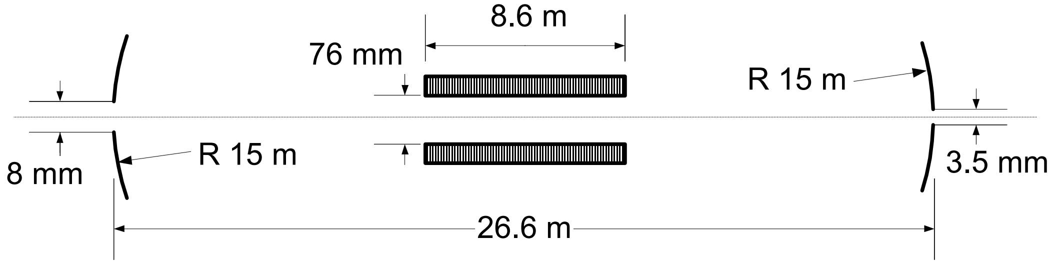

Figure 3: Scheme of the optical resonator.

RADIATION STUDY

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. 4. The preliminary simulation results [7] demonstrated a reasonable agreement with the measured data. The experimental curve is wider, that may be explained by the shortening of the optical resonator due to heating of the mirrors.

The average radiation power passed through the hole at the rear mirror was about 400 W. Taking into account the 7% loss, one get approximately 2 kW of power, extracted from the electron beam. The electron beam power was 200 kW. Therefore, the electron efficiency was about 1%. The FEL radiation parameters are listed in Table 2.

Table 2: The radiation parameters

Wavelength, mm	0.12...0.23
Minimum relative linewidth, FWHM	$3\cdot10^{-3}$
Pulse length, FWHM, ps	50
Peak power, MW	1
Repetition rate, MHz	11.2
Maximum average power, kW	0.4

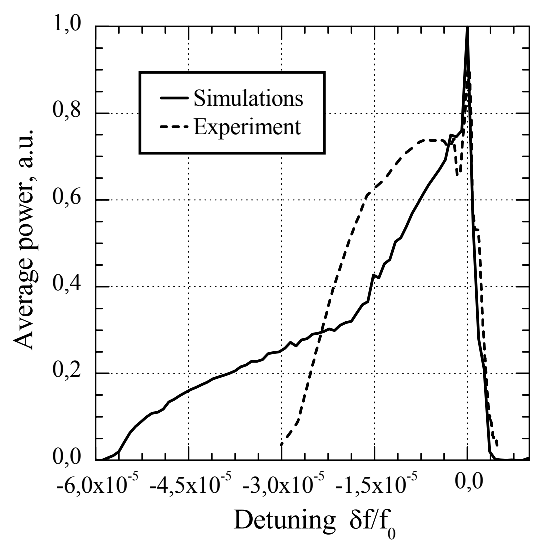

Figure 4: Dependency of the average power on the RF frequency detuning.

BEAMLINE AND USER STATIONS

An optical beamline from the accelerator hall to the user hall was built to transmit the radiation from the rear mirror hole to user stations. As the diffractional angular divergence $1.22\cdot\lambda/D \approx 0.03$ (for 200 micron) is high, the spherical mirror is used to transform the radiation beam to almost parallel one. The incidence angle is only 7 degrees, therefore its astigmatism is negligible (see Fig. 5). Other 5 mirrors are flat. The beamline is filled by dry nitrogen. It is separated from the accelerator vacuum by the diamond window, and from the air by polyethylene windows. After installation of nitrogen dryer we obtained almost complete transparency of the beamline.

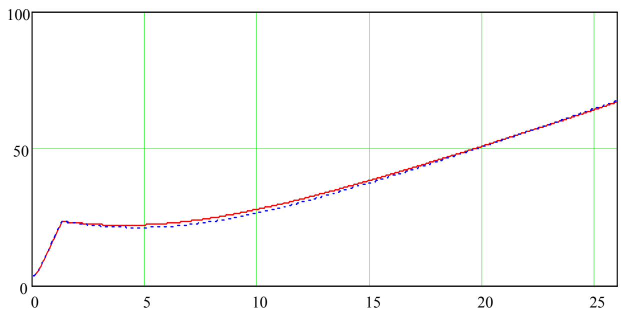

Figure 5: Calculated size of equivalent Gaussian beam (mm) vs. distance along the beamline (m).

Now radiation can be delivered to 5 stations. Two of them are used for measurement of radiation spectrum, and other three for users. In particular, selective terahertz ablation of DNA, proteins and other biologically relevant molecules was performed [8]. It was shown, that transfer from surface occurred without molecular destruction.

FURTHER DEVELOPMENTS

We plan to increase further the output power. The electron gun upgrade for the increase of the average current up to 0.1 A is in progress.

The design and manufacturing of the full-scale four-track accelerator is underway. An artistic view of the machine is shown in Fig. 6. The existing orbit with the terahertz FEL lies in the vertical plane. The new four tracks are in the horizontal one. One FEL will be installed at the fourth orbit (40 MeV energy), and the second one at the bypass of the second orbit (20 MeV energy).

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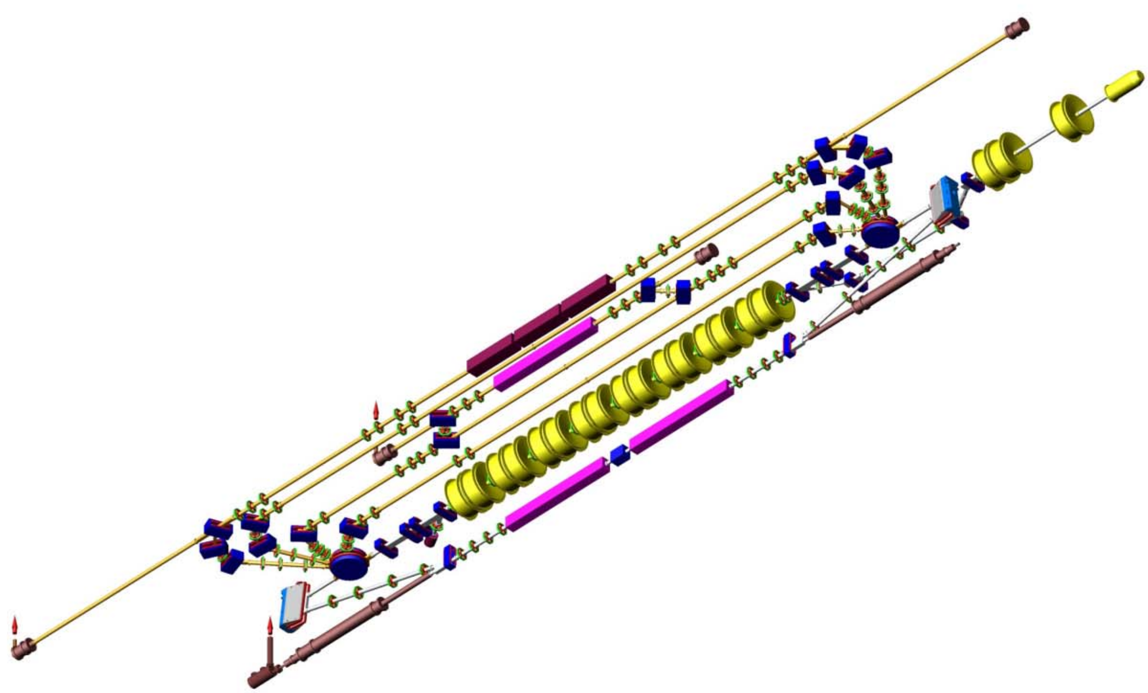

Figure 6: Scheme of the full-scale machine. The terahertz FEL track lies in the vertical plain while four others in the horizontal one.