DIAGNOSTICS OF BEAM LOSSES AT THE NOVOSIBIRSK FREE ELECTRON LASER

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INTRODUCTION

The Novosibirsk Free Electron Laser (NovoFEL) facility includes three free electron lasers (FEL), which are installed on the first, second and fourth tracks of a multi-turn accelerator-recuperator. The wavelength of the radiation of the first FEL is adjusted in the range of 110-240 µm. The radiation of this FEL consists of a periodic sequence of short pulses following each other with a repetition frequency of 5.6 or 11.2 MHz. The average radiation power can reach a value of 0.5 kW, and the peak power is 1 MW. The second FEL operates in the wavelength range of 40-80 µm. The repetition rate of the radiation pulses is 7.5 MHz, and the values of the average and peak powers coincide with the first FEL. The wavelength range of the third FEL is 5-20 µm.

During the generation of radiation in the undulator, the beam is microgrouped, accompanied by an increase in its energy spread. A beam with a large energy spread, passing through trajectory acquires a noticeable spatial spread, which leads to significant losses of the beam on the walls of the vacuum chamber and an increase in the radiation background.

The poster describes the three types of methods of beam losses diagnostic used in NovoFEL: a) observation of average losses at the first track, b) observation of losses from each bunch separately, and c) observation of losses from series of bunches in so-called "macro pulses" mode of generation of radiation.

DIAGNOSTICS IN MACRO PULSES MODE

A linear accelerator-recuperator is used as an electron source for NovoFEL. Using a linear accelerator-recuperator allows to obtain a large average current of electrons. It increases the average power of the laser generation. However, beam losses are also proportional to average beam current. Unfortunately, the more efficiency factor of the laser generation becomes, the greater the beam losses. This is due to the increasing energy spread of the bunch after passing through the undulator of the laser. The high energy spread in the electron bunches does not allow for continuous generation with maximum efficiency due to the strong radiation background that occurs. An acceptable level of background radiation is achieved in the mode of generation of radiation by macropulses. In this mode, a series of bunches with a duration of 1ms are followed with a frequency of 10ms.

To adjust such a mode, it becomes necessary to observe losses from each series of bunches, i.e. for 1 ms, followed by a 9 ms skip. To observe such losses in place No. 3 Cherenkov detectors in the form of quartz crystals were placed, the radiation from which is fed through an optical fiber to a PMT and digitized by an ADC with sampling frequency of 100 kHz developed by the BINP. Then the losses are averaged over many episodes and displayed to the operator on the computer screen.

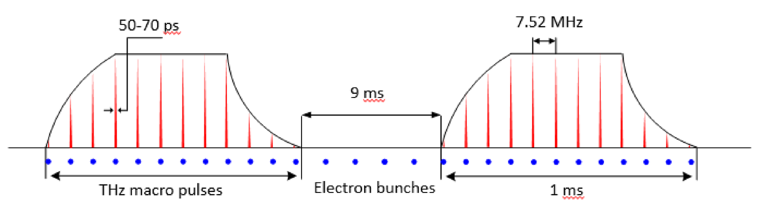

Figure: Mode of generation of the NovoFEL with macro–pulses (not in scale).

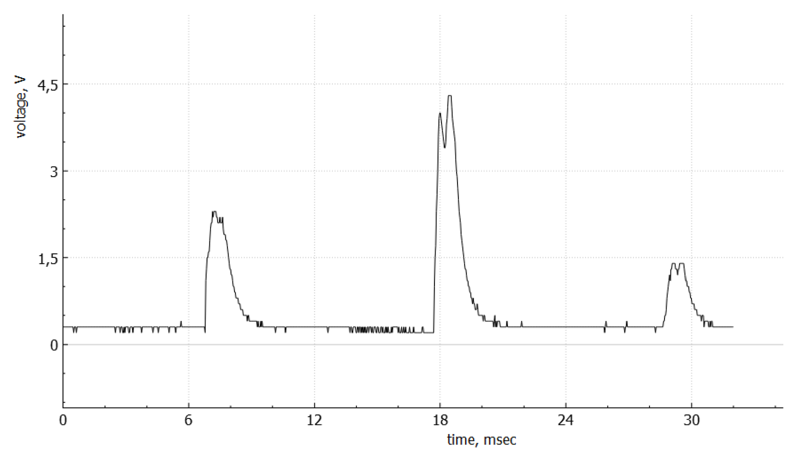

Figure: Typical view of losses in macro pulse mode of laser generation of the NovoFEL. Most losses are seen in first two milliseconds of 10-ms cycle.

Layout of NovoFEL

Table: Characteristics of accelerator-recuperator:

Parameter	1st FEL	2nd FEL	3rd FEL
Maximum energy, MeV	12	22	42
Operating current, mA	10	3.2	3.2
Repetition frequency of bunches, MHz	5.6	3.75	3.75
Emittance, µm x µrad	30	30	30
Operating frequency of resonators, MHz	180.4	180.4	180.4

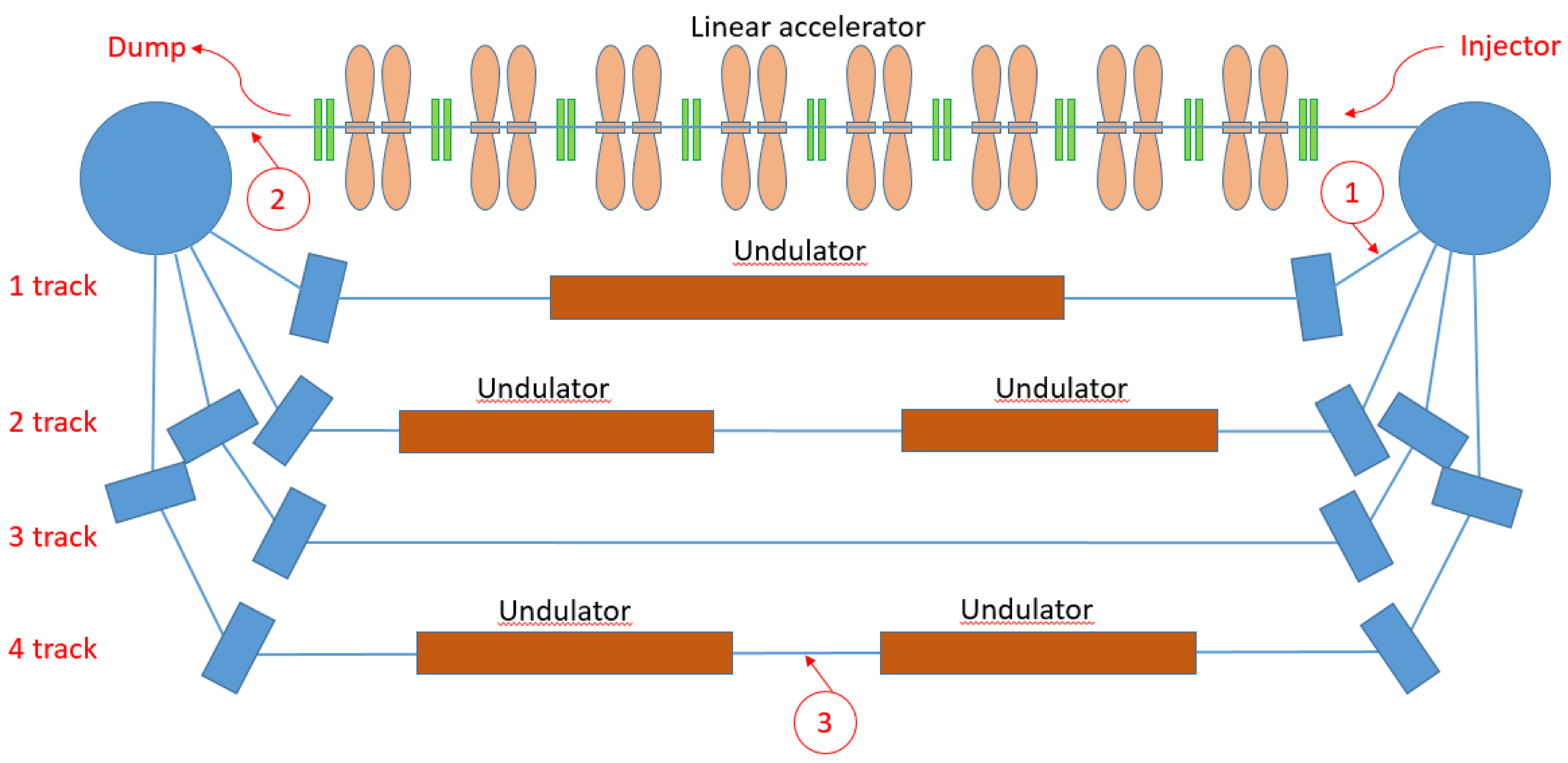

Figure: Layout of NovoFEL. Locations of detectors are marked in red circles: 1 – diagnostics of average losses, 2 – bunch-by-bunch diagnostics, 3 – diagnostics in macro pulses mode.

Table: Characteristics of radiation:

Parameter	1st FEL	2nd FEL	3rd FEL
Wavelength, µm	110-240	40-80	5-20
Maximum average power, kW	0.5	0.5-1	10
Maximum peak power, MW	1	1	10
Pulse duration, ps	30-120	20-40	10-20

DIAGNOSTICS OF AVERAGE LOSSES

The sensor is installed in the final part of the first track (marked with an arrow No. 1). Both accelerating and decelerating beams with a large energy spread pass through this place. As a result, a large heating of the walls of the vacuum chamber was observed in this place.

As a sensor was used a block of quartz, which is placed directly near the vacuum chamber. The beam, hitting the wall of the vacuum chamber, generates a shower of secondary particles in it, which, passing through the sensor, form Cherenkov radiation in the visible range in it. Visible radiation is transported through a fiber-optic cable to a photoelectronic multiplier, the signal from which is digitized by an ADC and displayed on the operator's computer.

This diagnostics uses slow ADC and PMT, and it shows the average losses from accelerating and decelerating beams over many bunches.

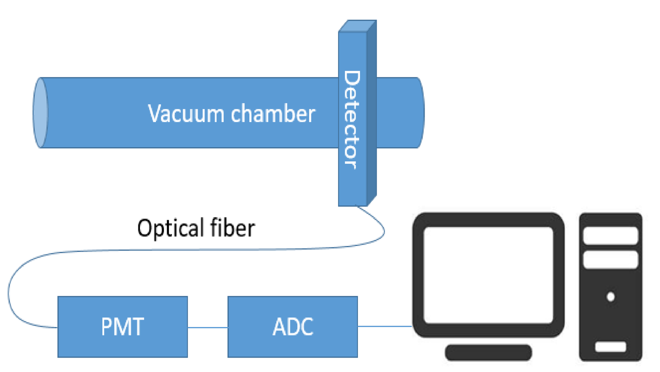

Figure: The layout of average losses diagnostics.

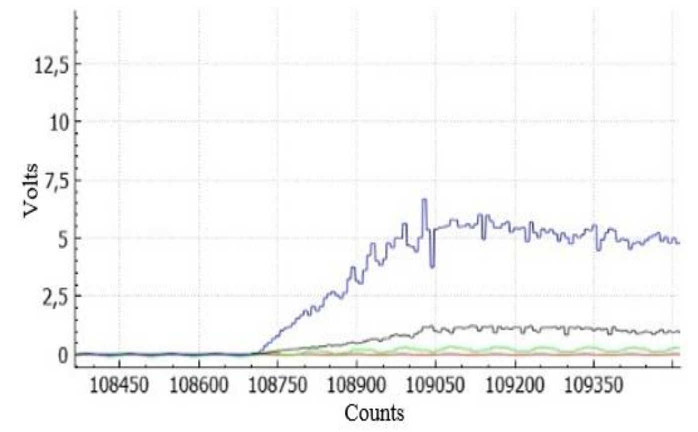

Figure: Increase of average losses while adjusting beam trajectory.

BUNCH-BY-BUNCH DIAGNOSTICS

Also, it is useful to know the losses from each individual bunch in order to adjust the passage of the beam along each of the tracks. For this purpose, in place No. 2, the vacuum chamber was wrapped with quartz optical fiber, which can work itself as a Cherenkov detector. When secondary particles from the vacuum chamber's wall occur in the optical fiber, Cherenkov radiation is generated, which is transmitted to the PMT, then the signal from the PMT is digitized by a high-speed ADC and displayed to the operator on the computer screen. To digitize the signals with duration about 10 ns, a high-speed ADC with a sampling frequency of 5GHz developed at the Budker Institute of Nuclear Physics (BINP) is used.

The time resolution of the ADC allows to observe the losses from each bunch separately.

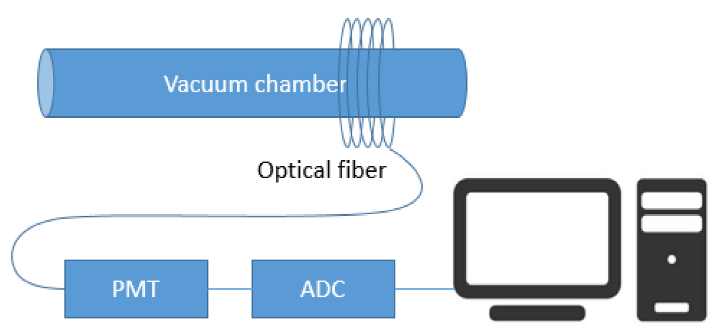

Figure: The layout of bunch-by-bunch diagnostics.

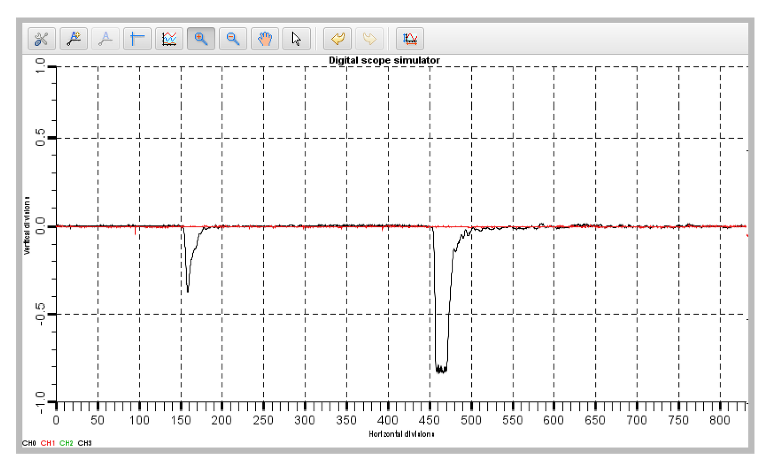

Figure: The typical signal from two bunches.

Table: Parameters of fast ADC used.

Parameter	Value
Model	Thorlabs FG550UEC
Modes	Multimode
Core diameter	550 µm
Operating wavelengths	250-1200 nm
Core material	Silica
Numerical aperture	0.22
Max attenuation (808nm)	10 dB/km

Table: Parameters of optical fiber.

Parameter	Value
Number of input channels	4
Bitrate	14
Bandwidth	0-150 MHz
Sampling rate	5 GHz, 4 GHz, 3 GHz, 2 GHz, 1GHz
Interface	Ethernet

REFERENCES

[1] Ya. V. Getmanov, O. A. Shevchenko, O. I. Deichuly, et al., “The Novosibirsk Free Electron Laser facility: current status and plans”, in *Proc. The 5-th Int. Conf. "Terahertz and microwave radiation: generation, detection and applications" (TERA-2023)*, Moscow, Russia, Feb. 2023, p. 49.

[2] Yu. I. Maltseva, S. V. Ivanenko, A. D. Khilchenko, “Beam loss monitoring system for the SKIF synchrotron light source”, *Journal of Instrumentation*, Vol. 17, Is. 5, 2022.

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