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MEASUREMENTS OF BEAM PARAMETERS AT THE LAST TRACK OF ERL-BASED NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

Parameters and dynamics of the electron beam of the Novosibirsk infrared Free Electron Laser (NovoFEL) are studied. The Novosibirsk FEL is based on the multi-turn Energy Recovery Linac (ERL). The ERL operates in CW mode with an average beam current of about 5 mA. Therefore non-destructive beam diagnostic methods are preferable. The beam energy at the last track of the ERL is 42 MeV. As a result, a significant part of synchrotron radiation from bending magnets is in the visible range and can be used for diagnostic purposes. Besides it, the diagnostics utilising optical transition radiation (OTR) is applied. The transverse beam dimensions were measured before (with OTR) and after (synchrotron radiation from a bending magnet) the undulator is applied for generating middle-infrared coherent radiation. The obtained data are used to calculate the Twiss parameters in the OTR observation point and beam emittance on the 4th track of the NovoFEL. The influence of the lasing on the transverse beam profile was studied as well.

INTRODUCTION

The Novosibirsk FEL facility [1] includes three FELs. All the FELs use the electron beam of the same multi-turn energy recovery linac. The layout of Novosibirsk FEL is shown in Fig. 1. The third FEL is installed on the fourth track of the ERL and electron energy here is 42 MeV. The beam from the injector is four times accelerated before it is used in the undulator of the third FEL. The used beam is four times decelerated in the same RF structure and absorbed in the beam dump.

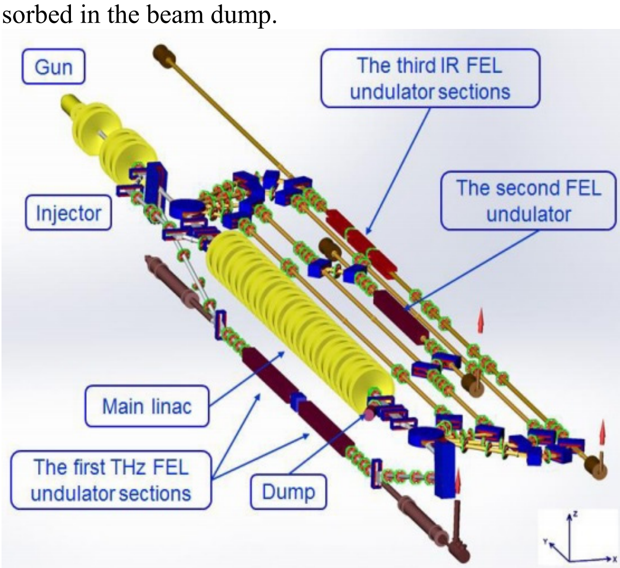

Figure 1: Layout of the Novosibirsk FEL.

The first lasing of the third FEL was obtained in summer 2015. The designed power is 1 kilowatt at a repetition rate of 3.75 MHz. Operation with implementation of the electron outcoupling scheme of laser radiation has started recently [2]. In order to tune it we have to know the incoming beam parameters. It is impossible just to calculate them because there are a lot factors influencing beam dynamics from the electron gun performance up to the accelerator lattice structure. Considering this problem it was proposed to organize a new beam diagnostics station in order to measure the Twiss parameters of the incoming electron beam.

BEAM DIAGNOSTICS

Diagnostics Overview

The diagnostics system for transverse size measurement consists of two optical stations, their position is shown by arrows in Fig. 2.

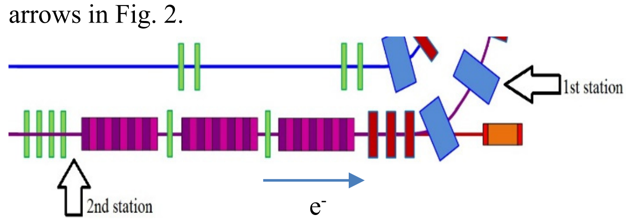

Figure 2: Optical stations of the 4th track of NovoFEL.

One station utilises the synchrotron radiation from the second bending magnet after undulator sections. It has been operating since 2016 [3]. For measurements of beam parameters before undulator sections which is crucial for electron out coupling tuning we decided to install new optical diagnostics using transition radiation (OTR) from Ti foil. The foil inserts into the vacuum chamber in the straight section of the 4th track of NovoFEL.

Technical Limitations

There are two main problems with the design of optical diagnostic systems. Synchrotron radiation of the beam (SR) has a divergence about 10^{-2} rad and it is difficult to deliver it out of the experimental hall without significant intensity loss. Another problem is a high residual activity created by the beam after half an hour operation of the third stage of NovoFEL. This problem affects both stations. Considering these restrictions, diagnostics tools have to be installed as close as possible to the optical output of the SR or OTR and a remote control of optics must be implemented.

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Layout of the Optical Stations

In order to cope with the mentioned above problems radiation hardened CID cameras 8726DX6 from Thermo Fisher Scientific are used to acquire a transverse beam profile (Fig. 3) [4]. A remotely controlled actuator is installed to control the position of the lens. The camera is radiation hardened but in order to increase its life time it was installed inside the additional radiation shielding. The first camera has been operating more for than 2 years without degradation of the image quality.

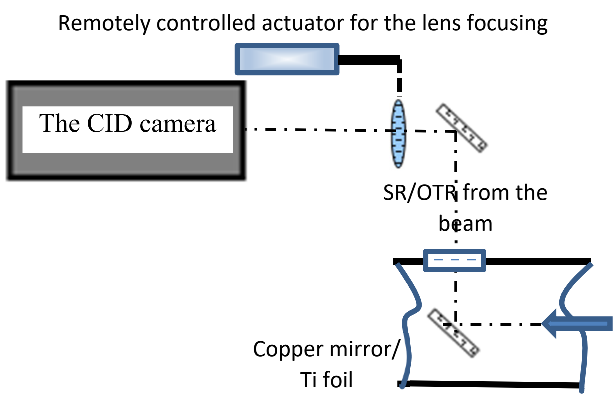

Figure 3: Layout of the 1st/2nd station for acquisition of the transverse profile of the beam with SR/OTR.

TWISS PARAMETERS MEASUREMENTS

We have used a quadrupole scan [5] technique for measurements of transverse beam emittance and Twiss parameters in the observation point of station 2. The beam dimensions as a function of the magnetic field strength of quadrupole magnet were acquired.

A quadrupole lens is selected four quads before an imaging station and the field strength is varied. Plotting the beam size as a function of K and applying a parabolic fitting function which yields three coefficients:

$$\Sigma_{11} = AKl^2 + BKl + C$$

Where Kl is the quadrupole field strength, D is the transport matrix form (including) varied quadrupole to optical station. The beam matrix element Σ_{11} can be equated to the beam transfer matrix, which upon solving gives the beam matrix elements and then we obtain Twiss parameters:

$$\varepsilon = \frac{\sqrt{AC}}{{D_{12}}^2}, \quad \alpha = \sqrt{\frac{A}{C}}\left(B + \frac{D_{11}}{D_{12}}\right), \beta = \sqrt{\frac{A}{C}},$$

$$\gamma = \frac{{D_{12}}^2}{\sqrt{AC}}\left(AB^2 + C + 2AB\left(\frac{D_{11}}{D_{12}}\right) + A\left(\frac{D_{11}}{D_{12}}\right)^2\right),$$

Emittance Measurements

The beam image acquired by the OTR and SR monitors transition radiation with transverse profiles is presented in Fig. 4. The vertical and horizontal projections of the OTR beam image are shown in Fig. 5. OTR images can be fitted by Gaussian curve, but SR profile is obviously non-Gaussian (Fig. 4).

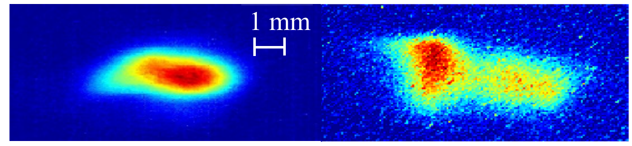

Figure 4: Image of the beam acquired by the OTR monitor, $I_b \approx 20$ mkA (left). Image of the beam acquired by the SR monitor, $I_b \approx 2$ mA (right).

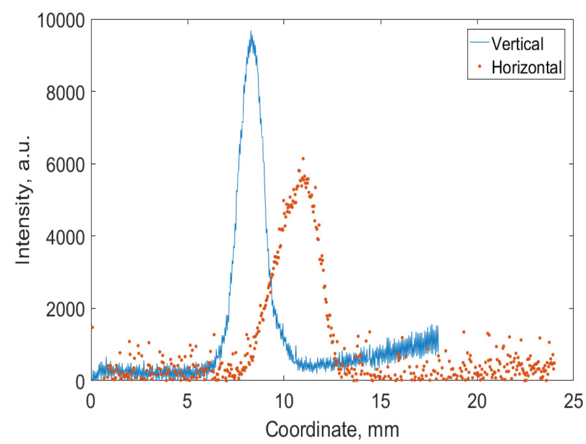

Figure 5: Beam profiles acquired by the OTR monitor.

Altering the field strength of the selected quadrupole we recorded the dependence of beam transverse dimensions measured with OTR versus the strength of quadrupole magnetic field (Fig. 6).

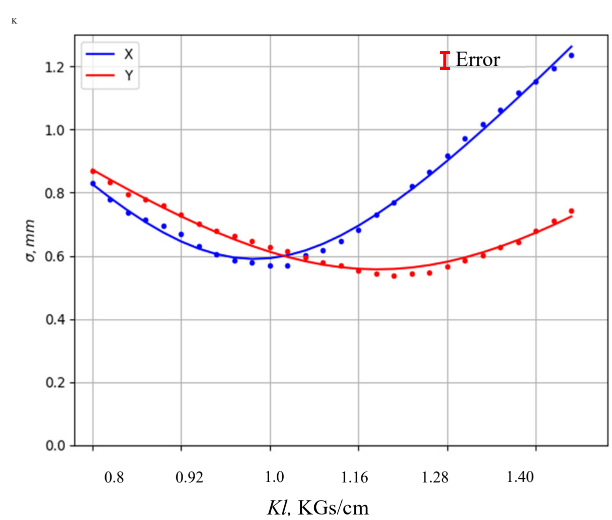

Figure 6: Measured dependence of transverse beam dimensions obtained with OTR vs strength of quadrupole lense.

Fitting the data we have computed Twiss parameters and the vertical and horizontal beam emittance (Table 1). The obtained values are in reasonable agreement with numerical model of installation.

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Table 1: Measured Beam Parameters

Parameter	X	Y
ε, m	$1.56 \cdot 10^{-6}$	$5.17 \cdot 10^{-7}$
α	2.838	-2.241
β	5.290	23.938

Using the measured parameters we have calculated the vertical beam size at the point of observation of the second optical station. The calculated value is σ_z=0.9mm which is in good agreement with experimentally acquired beam dimension.

Influence of the Lasing on the Beam Profile

After undulator sections the horizontal beam profile is non-Gaussian (Fig. 7). The optical functions of the around the observation point of station 1 are presented in Fig. 8. The significant dispersion function η_x makes the transverse beam profile strongly dependent on the energy distribution of particles. Hence it is not easy to decide what we can call a "beam size" in order to compare it with Gaussian distribution.

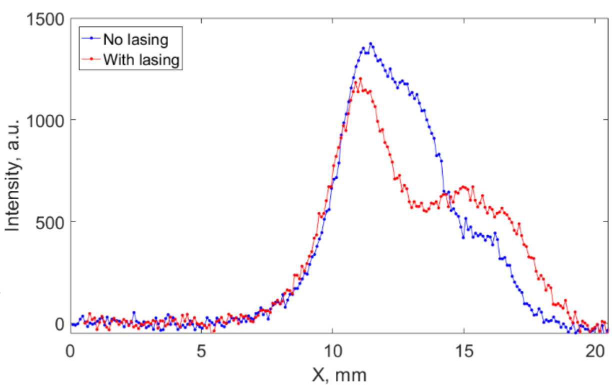

Figure 7: Influence of lasing on horizontal beam profile after undulator sections.

Two horizontal beam profiles with and without lasing are shown in Fig. 8. It is clearly seen that the presence of lasing greatly affects the horizontal beam profile (while the vertical profile remains unchanged). It is proposed that this influence is caused by the change in energy distribution after the beam passes through the undulator sections.

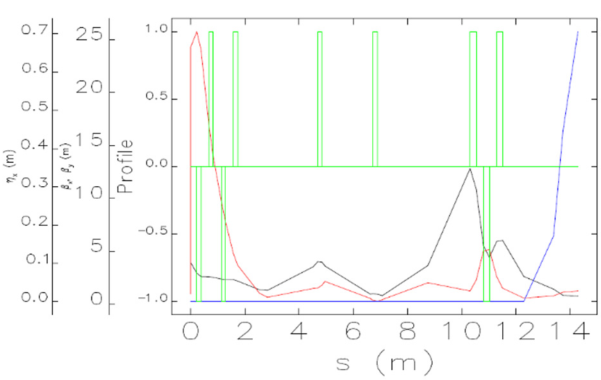

Figure 8: Optical functions from first of four varied quads up to 1st optical station. Blue line - η_x, red line – β_x, black line – β_y.

In order to calculate horizontal particle distribution we need to know not only the initial particle distribution but also the initial energy distribution and we need to track this distribution through the undulator sections. The results of the simulations are presented in Fig. 9. The initial energy distribution was assumed to be Gaussian with σ_E =0.002%.

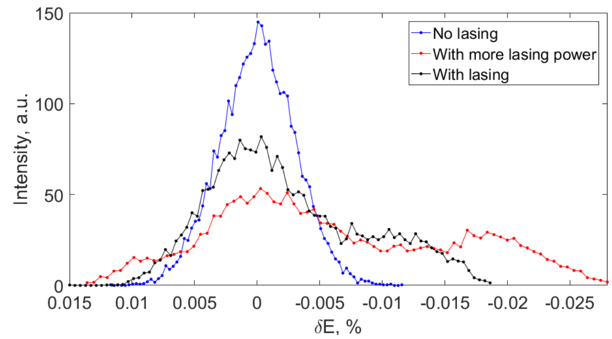

Figure 9: Simulations of energy distribution distortion under an influence of the lasing.

CONCLUSION

The second optical diagnostics station was installed and comissioned on the NovoFEL. The vertical and horisontal beam emittance was measured from the obtained data. The measured beam parameters are used for electron outcoupling tuning. The experimentally observed influence of the lasing on the radial beam profile is in qualitive agreement with the numerical simulations. We plan to carry out a detailed study of the beam energy distribution at the 4th track of the NovoFEL in the nearest future.

ACKNOWLEDGMENTS

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