AN EXPERIMENTAL STUDY OF BEAM DYNAMICS IN THE ERL-BASED NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

Transverse and longitudinal dynamics of the electron beam of the Novosibirsk infrared Free Electron Laser is studied. The Novosibirsk FEL is based on the multi-turn energy recovery linac (ERL). The ERL operate in CW mode with an average current about 10 mA. Therefore non-destructive beam diagnostics is preferable. The beam energy at the last track of the ERL is 42 MeV. As a result, significant part of synchrotron radiation from bending magnets is in the visible range. The transverse beam dimensions were measured with the optical diagnostics before and after the undulator applied for generation of middle-infrared coherent radiation. The obtained data is used to calculate the beam energy spread and emittance. The longitudinal beam dynamics was studied with electro-optical dissector.

INTRODUCTION

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

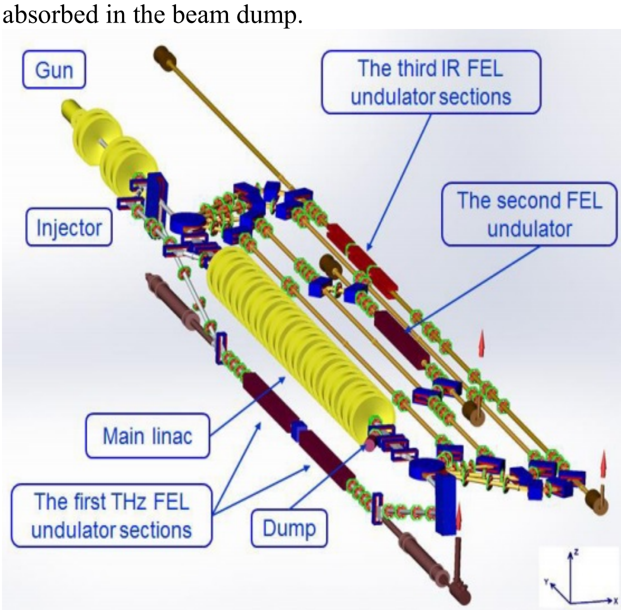

Figure 1: The Novosibirsk FEL.

The first lasing of the third FEL was obtained in summer 2015. The designed power is 1 kilowatt at repetition rate 3.75 MHz

EXPERIMENTAL SETUP

Synchrotron Spectrum

The Novosibirsk FEL applies the energy recovery technology. The beam energy in the third stage of NovoFEL is 42 MeV. It allows us to use a synchrotron radiation from the bending magnets for optical diagnostics of the parameters of the beam. The bending radius in magnets before and after the fourth track is 0.655m. The calculated spectrum of synchrotron radiation is presented in Fig. 2.

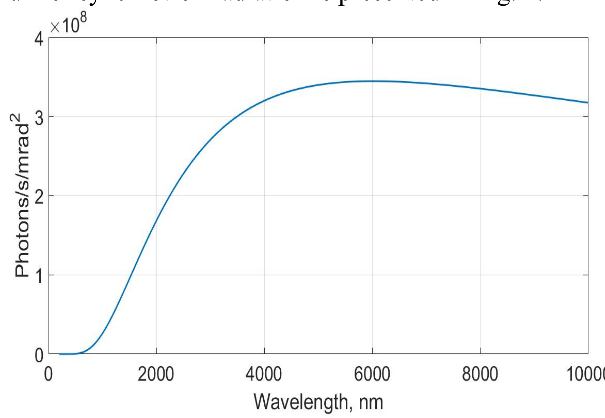

Figure 2: Synchrotron radiation from the bending magnet of the third FEL.

Critical wavelength of the spectrum is 5016 nm. There are enough photons in optical wavelength range to acquire the synchrotron radiation and measure the bunch parameters.

Technical Limitations

There are two main problems with the design of optical diagnostic systems. Synchrotron radiation of the beam 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–hour operation of the third stage of NovoFEL. Considering these restrictions, diagnostics tools have to be installed as close as possible to the optical output of the bending magnet and a remote control of optics must be implemented.

Transverse Sizes Measurement

Radiation hardened CID camera is used to acquire transverse beam profile (Fig. 3) [2]. The camera receives the synchrotron radiation from the bending magnet placed after the undulator.

ISBN 978-3-95450-182-3

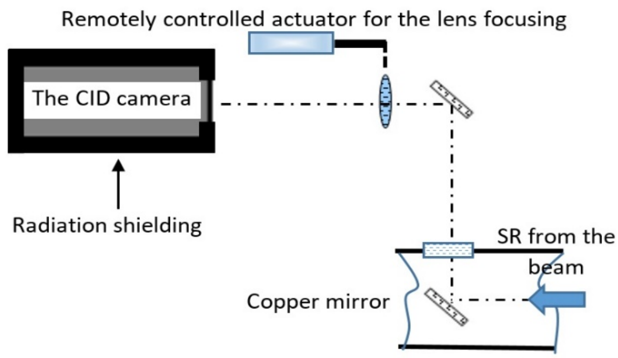

Figure 3: Layout of the diagnostics for acquisition of the transverse profile of the beam.

Remotely controlled actuator is installed to control a position of the lens. Camera is radiation hardened but in order to increase its life time it was installed inside the additional radiation shielding.

Longitudinal Profile Measurement

The electron-optical dissector [3] was applied for measurement of the longitudinal profile of the beam (Fig. 4). The dissector can be installed in the area with high residual activity without significant degradation in performance. It is positioned at the entrance of the fourth track.

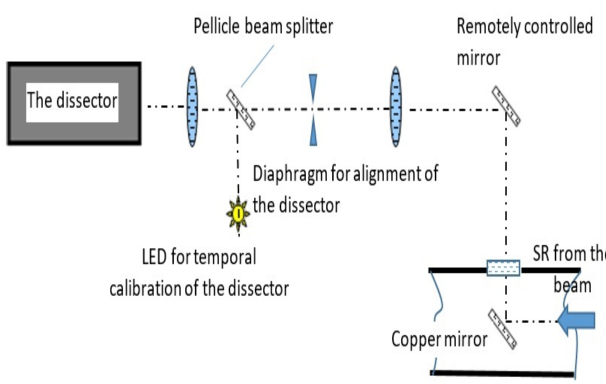

Figure 4: Layout of the diagnostics for acquisition of the longitudinal profile of the beam.

The preliminary alignment of the projection optics was made with the CCD camera instead of the dissector. The beam image was focused on the plane of the diaphragm (Fig. 4) that was controlled by the CCD. At the next step an image of the diaphragm was focused on the photocathode of the dissector.

RESULTS

The longitudinal charge distribution is not obtained yet. The example of transverse image is shown in Fig. 5. The distribution has a long radial “tail”. In order to check if it belongs to beam or it is a stray light from the walls of vacuum chamber a series of shifted bunch profiles was recorded. Shape of the tails on the acquired images remained the same. Therefore, the tail is considered as a part of the beam. Nevertheless, we are going to study the instrumental function of the diagnostics more detailed.

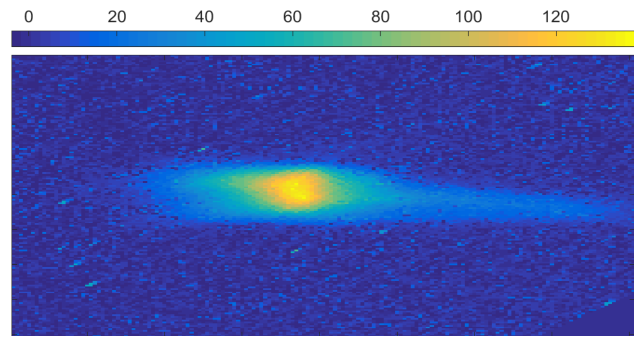

Figure 5: An example of transverse distribution.

Transverse profiles of the beam were recorded during two runs with a different lasing power. Vertical beam profile was fitted well by Gaussian curve and remained constant within an accuracy of the measurements during both runs independently on the lasing power.

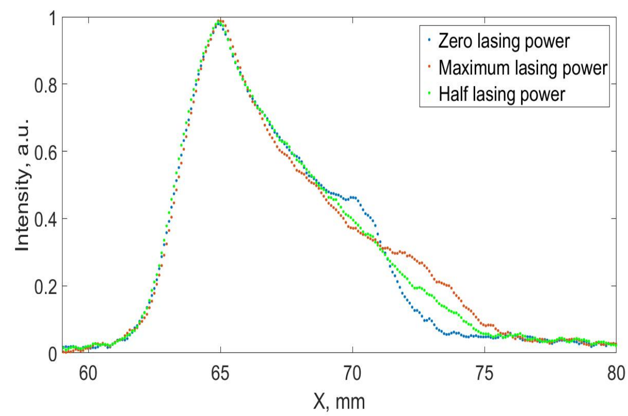

Figure 6: Horizontal profiles acquired during the 1st run.

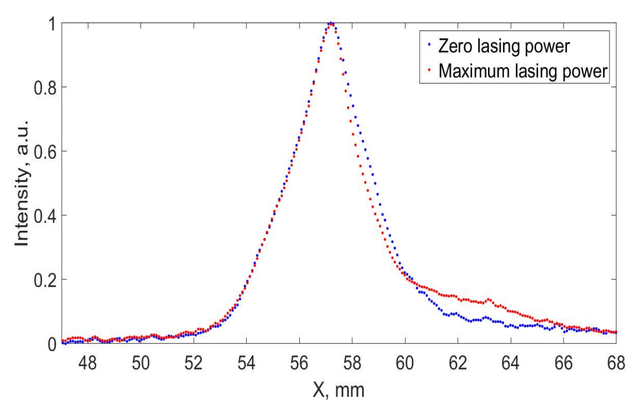

Figure 7: Horizontal profiles of the beam acquired during the 2nd run.

Radial beam shape was different in these runs but its behaviour during the lasing power increase was the same. The peak of the distribution was not moving in any direction. At the same time the “tail” started to grow with the increase of the lasing power (Fig. 6, 7). Parameters of the “tail” were studied. For this purpose, each horizontal distribution in each run was normalized to the integrated

ISBN 978-3-95450-182-3

intensity of the acquired light and the difference of the profiles was computed. We interpret the obtained distribution as a change of the beam appearing due to lasing (Fig. 8).

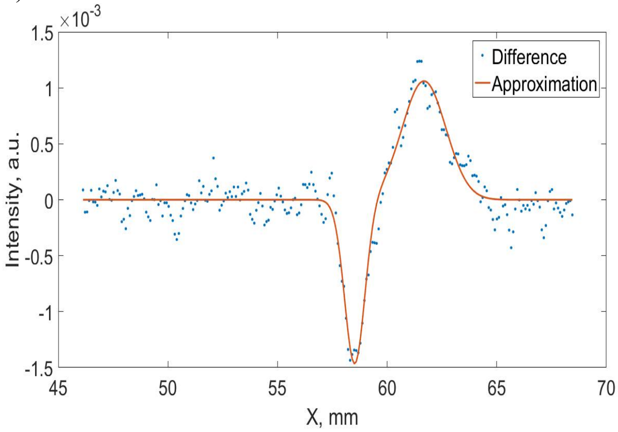

Figure 8: An example of tail structure.

The distribution consists from two peaks which can be fitted by Gaussian curve. The squares under the curves, i.e. the number of particles relates to the peaks is the same within limits of measurement accuracy. The positive peak corresponds to the low-energy electrons. Considering that the electrons lose an energy due to lasing and shift from the negative peak to the positive, the lasing power can be calculated from the following equation.

$$P = \frac{kIE\Delta x}{\eta}. \quad (1)$$

Where P is the lasing power, N is the number of electrons, k is the integral of peak, E is the energy of the beam, η =0 .49m is the dispersion at the measurement point, Δx is the distance between the peaks. Another approach to estimate the lasing power is to calculate average beam energy loss. In this case k=1, Δx is the average shift of the beam. Average beam shift was calculated as the shift of the center of mass of the complete distribution function. The lasing power was calculated for the beam current of 3 mA (Fig. 9, 10).

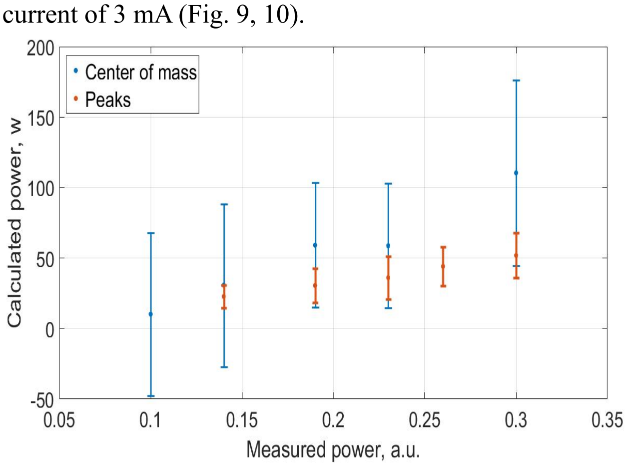

Figure 9: Comparison of the two approaches of estimation of the NovoFEL power (1st run).

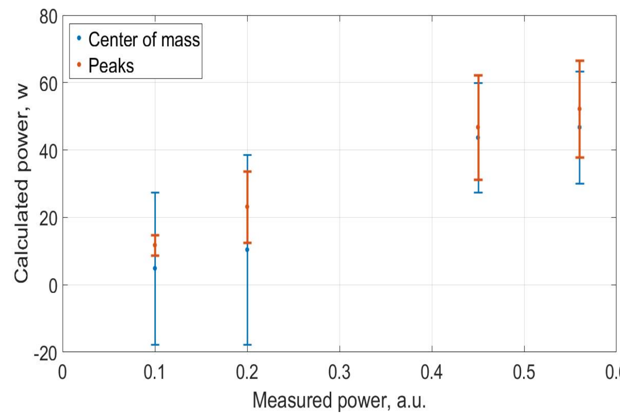

Figure 10: Comparison of the two approaches of estimation of the NovoFEL power (2nd run).

The absolute error of the both methods is significant yet and obtained results should be treated as just very preliminary. Nevertheless, the data of the both approaches do not contradict each other and the lasing power estimated by them is in a reasonable agreement with the expected value.

CONCLUSION

The optical diagnostics for the measurement of the transverse beam profile of the third stage of the NovoFEL is commissioned. Dependence of the transverse distribution of the beam on the lasing power is studied. The energy loss of the beam is calculated from the shift of the centre of mass of the radial distribution of the beam. Another approach is to calculate the energy loss from the ”tail” of the radial distribution appearing due to lasing. The data of the both methods are in a satisfactory agreement, but we still need more information to study the behaviour of the ”tail” during lasing. The study should be supplemented by the measurements of the longitudinal distribution of the beam.

ACKNOWLEDGMENT

The presented experimental results were implemented due to financial support of the Russian Science Foundation (project No. 14-50-00080).

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