THE STUDY OF THE ENERGY RECOVERY EFFICIENCY AT NOVOSIBIRSK FEL ERL*

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Abstract

12 MeV energy recovery non-superconducting linac of the Novosibirsk terahertz free electron laser (FEL) is put into operation in 2003 [1]. In this work the efficiency of energy recovery was studied. The transversal and longitudinal beam halo was investigated by studying the dependence of the beam dump current on steering corrector strength and RF system parameters.

INTRODUCTION

Main parameters of the Novosibirsk FEL and driving energy recovering linac (ERL) are summarised in Table 1. The accelerator layout is shown in Fig. 1.

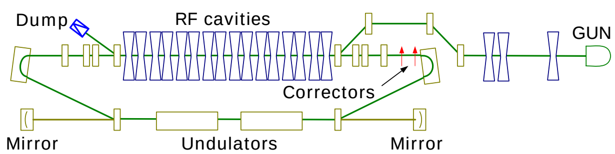

Figure 1: Schematic layout of the Novosibirsk FEL.

Table 1: Achieved parameters of the Novosibirsk FEL and ERL

RF frequency, MHz	180.4
Beam frequency, MHz	11.2
Bunch charge, nC	2
Current, mA	20
Beam energy, MeV	12
Energy recovery efficiency	>98%
Laser wavelength, μm	120÷240
Laser power, W	400

Due to high average power in the beam (up to 200 kW), problem of high energy recovery efficiency is essential. Beam losses lead to heating of the accelerator vacuum chamber, high X-ray level in the accelerator hall, and radioactive contamination.

We attempted to optimize beam losses measuring the acceptance of the accelerator channel by pairs of nearby correctors.

ACCEPTANCE MEASUREMENTS

Unlike storage rings [e.g. 3], measuring acceptance of a linac is quite simple and straightforward procedure. The accelerator acceptance is measured by a pair of nearby correctors. The scheme of the experiment is shown in Fig. 2. Correctors vary the beam position and angle, and the current from a Faraday cup in the beam dump is measured. The measurements must be carried out at low beam repetition rate (23 kHz, average current about 40 μA) since full beam losses occur.

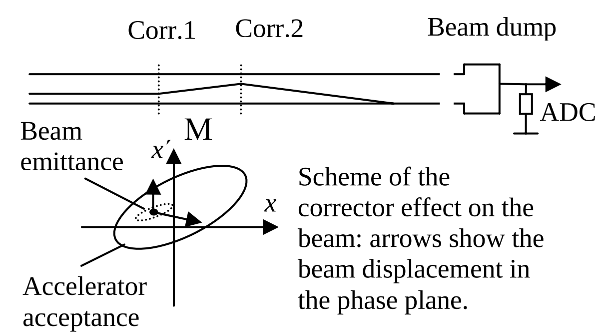

Figure 2: Scheme of the linac acceptance measurements. Two correctors are used to change the beam position and angle.

As an example in Fig. 3 we show results for a pair of 'y' correctors lying before deceleration (shown in Fig. 1.). The measurements are made on a grid of 25x25 points. Correctors' strength is chosen to make a rectangle in the axis of acceptance ellipse in order to minimize the number of measurements. Each point takes about 3 seconds to measure due to slow magnetic system adjustment. So the overall time to measure acceptance in one point is about 10 minutes.

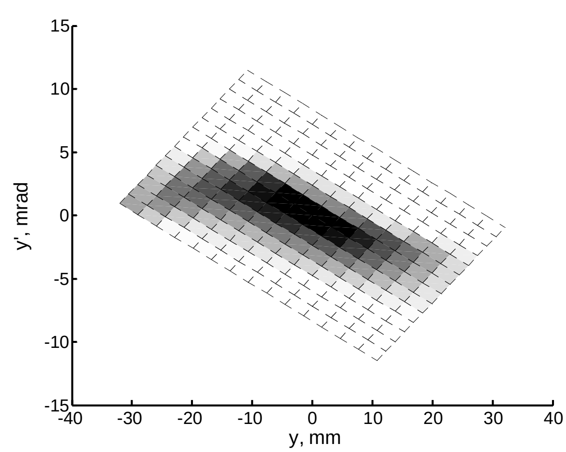

Figure 3: Sample results of the acceptance measurements.

Corrector strength calibration and transport matrix of the system between the correctors is needed to calculate the coordinates and angles in the phase plane. In this case we used calculated transport matrix from Trace3D code [2].

* The work was partially supported by SB RAS grant N174/06 and by grant №2.1.1.3846 of Russian Ministry of Science and Education.
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Fig. 4 shows the same results as Fig. 3 but contour lines for normalized dump current levels 0.184, 0.5, and 0.816 are drawn. The area of the 0.5 level contour plot (S_0) is the channel acceptance. Analysing areas of other two contours (S_+, S_-) one can estimate the beam emittance. If we assume the emittance and acceptance ellipses to be similar, one can derive for emittance the following formulas:

$$\varepsilon = S_0 + S_\pm - 2\sqrt{S_0 S_\pm} \text{ and } \varepsilon = \left(S_+ + S_- - 2\sqrt{S_+ S_-}\right)/4$$

In this example the channel acceptance is 57 mm·mrad, and the emittance is estimated as 4 mm·mrad.

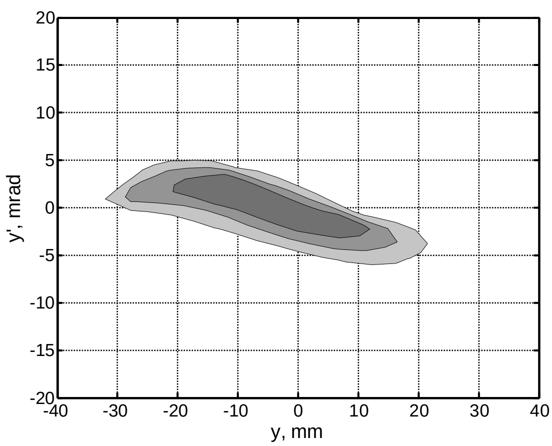

Figure 4: Contour lines of the normalized dump current. 'y' plane. Levels are 0.184, 0.5 and 0.816.

One can estimate the expected acceptance as $\varepsilon_{acc} \sim r^2/L$, where r is the accelerator vacuum chamber radius (40 mm in our case) and L is the distance between focusing lenses (~1.6 m in our case). We expect the beam losses to occur after deceleration before dump, so this is the acceptance of low energy beam (E_0=1.7 MeV). The acceptance for E_1=12 MeV beam before deceleration is then γ_1/γ_0 times smaller. Substituting these values we get ε_{acc}~150 mm·mrad, which coincides with the measurements on the order of magnitude.

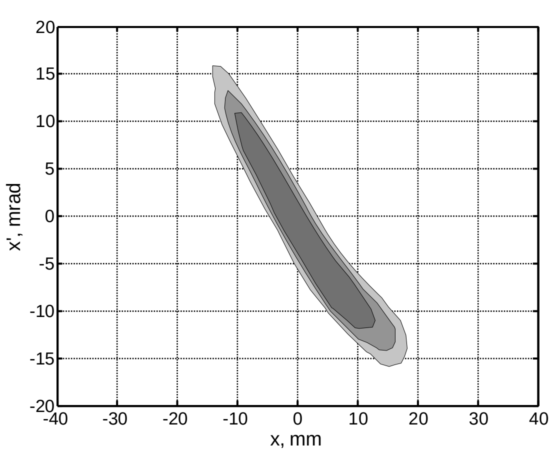

Figure 5: Acceptance measurement in 'x' plane.

Similar results for a pair of 'x' correctors located in the same place are shown in Fig. 5. The acceptance is 54 mm·mrad, beam emittance is estimated as 1.5 mm·mrad.

Another example is the measurement of the longitudinal acceptance. We cannot control the longitudinal variables before deceleration, so in this case we controlled the electron gun voltage and electron bunch delay (i.e. we measured the acceptance from the gun to the dump). The result of these measurements is shown in Fig. 6. Zero time delay and ΔE correspond to our usual working regime. Maximal ΔE in the figure is limited by the gun power supply but the contours are predictable in the cut off area. The channel longitudinal acceptance is about 8 ns·kV, and the beam emittance is about 0.5 ns·kV.

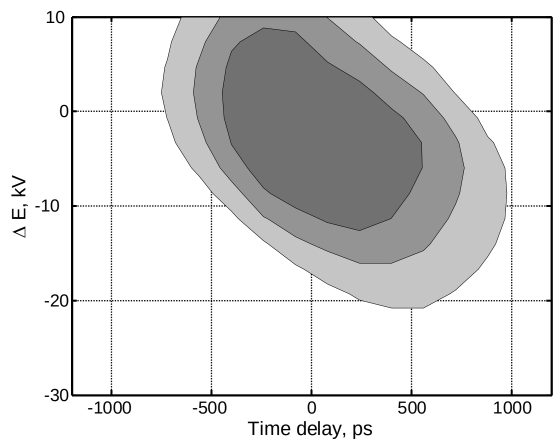

Figure 6: Contour lines of the normalized dump current for longitudinal correctors: gun voltage and electron bunch delay. Levels are 0.184, 0.5 and 0.816.

DISCUSSION

Linac acceptance can be measured varying two nearby correctors and measuring the dump current.

At the same time, the beam emittance is measured. Though the accuracy of the emittance measurement is not high, the result can be treated as an upper estimate.

Cubic nonlinearity clearly seen in figures 3 we attribute to aberrations of vertical focusing by injection chicane. There are 16 quadrupoles downstream of the correctors in this example. Their contribution to the nonlinearity seems to be less significant.

It should be noted that the measurements are carried out at low beam repetition rate without lasing. The beam emittance with lasing is spoiled by the energy spread in the beam and the results would be somewhat different especially for 'y' and longitudinal phase plane.

REFERENCES

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