TRANSVERSE EMITTANCE MEASUREMENTS IN HIGH-POWER FIR FEL ENERGY-RECOVERY LINAC

D.A. Kayran, A.N. Matveenko, O.A. Shevchenko, N.A. Vinokurov
Budker Institute of Nuclear Physics, 11 Acad. Lavrentyev Prosp., 630090, Novosibirsk, Russia
Email:A.N.Matveenko@inp.nsk.su

Abstract

50 MeV accelerator-recirculator of Siberian Center for Photochemical Research has been designed to drive the FIR FEL with an average power of up to 10 kW in the wavelengths region from 5 to 200 µm. The first stage with the beam energy of 14 MeV was put into operation and laser power of about 200 W on 150 µm was achieved recently [1]. Transverse emittance measurements are carried out online in a number of locations along the beam-line. OTR screens and video-cameras are used to capture the beam shape images, video signal is digitized by a frame grabber and the pictures are processed further. Online measurements allow the accelerator parameters to be optimized to minimize the emittance growth, which is essential to the FEL operation. The transverse emittance measurements system and data processing techniques are presented in this paper.

INTRODUCTION

The scheme of the first stage of the accelerator-recirculator is shown in Fig.1 and the accelerator parameters are given in Table 1.

From a number of possible approaches [2,3] to realization of transverse emittance measurements system we have chosen an optical transition radiation (OTR) screens with optical registration of transversal charge density distribution.

There are a 7 OTR screens along the beam line. Some of them are located behind bending magnets, and some can be inserted by remotely controlled motors. The beam emittance is measured at low bunch repetition rate (usually 22 kHz, which is the lowest possible frequency at the installation now, or a small multiple of it).

Table 1: Accelerator parameters (the first stage)

RF wavelength, m	1.66
DC Gun accelerating voltage, MV	0.28
Injection energy, MeV	1.8
Final electron energy, MeV	12
Bunch repetition rate, MHz	0.0225 – 22.5
Average current, mA	0.01 – 40
Beam emittance, mm· mrad	1
Final electron energy spread, %	1
Final electron bunch length, ns	0.02 – 0.1
Final peak electron current, A	40 – 10

The beam density distribution is measured at different currents in focusing solenoids or quadrupoles before the OTR screen. For the beam size measurement we use standard household CCD camera (calibrated to give linear response) and a video adapter with a frame grabbing capability. The pictures of the beam are stored in a single ".avi" file. This file is processed further by a MATLAB program with graphical user interface which allows to set all necessary parameters and choose the approximation method for the density distribution (standard distributions gaussian or waterbag or, alternatively, the r.m.s. beam size is calculated).

The beam parameters (horizontal and vertical emittances and Twiss parameters) can be calculated in the following way. If we assume a system with the transport matrix from the focusing lense to the OTR screen t_{ij}, the Twiss parameters are transformed according to

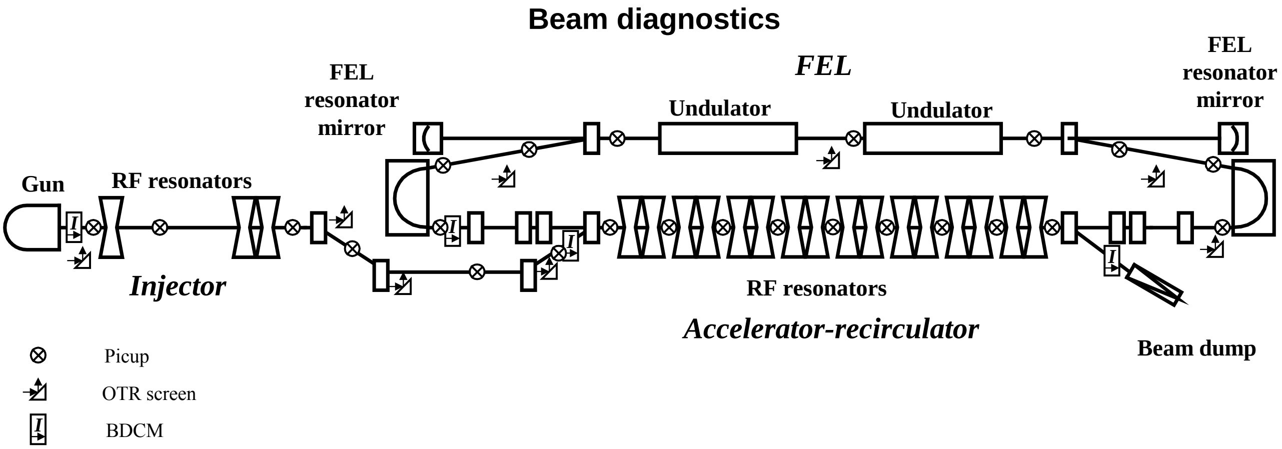

Fig. 1: Energy-recovery LINAC beam diagnostics.

$$\begin{pmatrix}\beta\\ \alpha\\ \gamma\end{pmatrix} = \begin{pmatrix} t_{11}^2 & -2t_{11}t_{12} & t_{12}^2 \\ -t_{11}t_{12} & t_{11}t_{22}+t_{12}t_{21} & -t_{12}t_{22} \\ t_{21}^2 & -2t_{21}t_{22} & t_{22}^2\end{pmatrix}\begin{pmatrix}\beta\\ \alpha\\ \gamma\end{pmatrix}_0 .$$

In a simplest case of a thing lens with a strength *P* and a drift *L* the transport matrix is

$$t_{ij} = \begin{pmatrix}1 & L\\ 0 & 1\end{pmatrix}\begin{pmatrix}1 & 0\\ P & 1\end{pmatrix} = \begin{pmatrix}1+LP & L\\ P & 1\end{pmatrix}$$

and the square of the beam size on the OTR screen is given by

$$w^2 = \varepsilon\beta = \varepsilon\left((1+LP)^2\beta_0 - 2L(1+LP)\alpha_0 + L^2\gamma_0\right)$$

which is parabolic with respect to the lens strength P. Fitting the measured squared beam sizes by a parabola one can get the beam Twiss parameters on the lens. Practically, beam size measurement, residual magnetic fields, and space charge effects are the problems to deal with by the data processing.

DATA PROCESSING EXAMPLE

An example of the measurement results is shown in Fig.2. Here the beam size is measured on the OTR screen after the first bending magnet in the injector channel. The current in a focusing solenoid before the bend is changed. Bunch charge was suppressed to about 0.3 nC and buncher resonator was switched off in this experiment to decrease the space charge effects. Accelerating RF cavities were also switched off (the beam energy was about 280 keV).

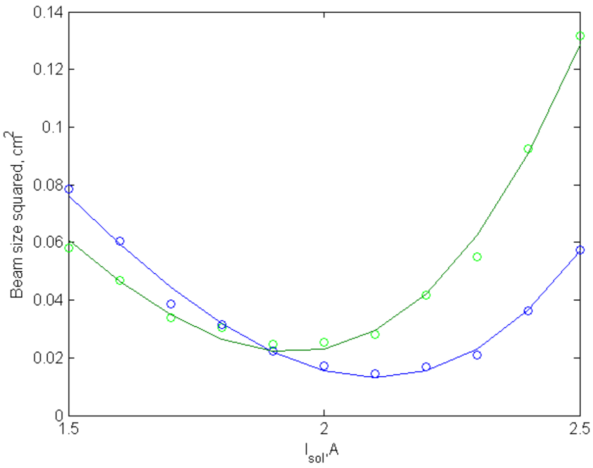

Fig.2: Squared beam size vs. focusing solenoid current. Circles are measured points for x and y direction, lines are approximations.

Although the statistical error of the measured beam parameters is small (<5%), systematic errors must be eliminated to give accurate results. Two of the possible sources of error are estimated below.

First, the camera resolution must be good enough. If the point size due to camera resolution is r_0, ε is the beam emittance, β_0 is the beam Twiss parameter on the lens, L is the distance from the lens to the OTR screen, then the measured emittance is

$$\varepsilon'^2 = \varepsilon^2 + \frac{\varepsilon\beta_0 r_0^2}{L^2}$$

Therefore, the camera resolution r_0 must be

$$r_0 << L\sqrt{\frac{\varepsilon}{\beta_0}}$$

which is quite strong restriction (especially for high energy beam, when emittance is small) that forced us to use supplementary optics.

Second, residual magnetic field in the drift must be small enough. If we assume the transport matrix from the lens to the OTR screen to be

$$\begin{pmatrix}\xi & \eta L\\ t_{21} & t_{22}\end{pmatrix},$$

the measured emittance will be η^2 times larger, than the real one.

$$\varepsilon' = \varepsilon\eta^2$$

This must be taken into account especially for a low energy beam in the injector. Although we have only solenoidal optics in the injector the beam vertical and horizontal Twiss parameters and emitances in Fig.2 are different. We suppose this difference to be due to residual fields in a quadrupole located between the last solenoid and the OTR screen, which was switched off but not demagnetized during the experiment.

CONCLUSION

Up to now a number of emittance measurements were carried out in the injector to optimize the beam optics. The main results are

- Beam density distribution in a bunch is close to parabolic (waterbag distribution)
- RF cavities phase and the buncher amplitude tuning can vary the beam normalized emittance from 15 to 30 micron

The emittance measurement system is in operation now. Experiments to improve the beam quality for FEL operation are being carried out.

ACKNOWLEDGEMENTS

One of the authors acknowledges partial financial support of “Russian Universities” program under the grant ur.01.01.029.

REFERENCES

[1] E.A.Antokhin et all, Problems of Atomic Science and Technology, p.3-5, №1, 2004.

[2] “High quality beams”, Joint Accelerator School, St.Petersburg and Moscow, Russia, 2000.

[3] “Beam Measurement”, World Scientific, Proceedings of the Joint US-CERN-Japan-Russia School on Particle Accelerators, Switzerland, 1998.