BEAM EMITTANCE MEASUREMENT FOR THE NEW FULL ENERGY INJECTOR AT ELETTRA

G. Penco*, L. Badano, S. Bassanese, G. Ciani, P. Craievich,
S. Di Mitri, M. Ferianis, M. Veronese, M. Predonzani (*Sincrotrone Trieste, Italy*),
A. Lutman, (*DEEI, Trieste*)

Abstract

An emittance measurement station was set up and operated with the quadrupole scan technique to characterize the electron beam transverse phase space at the Booster pre-injector end. The diagnostic station, based on a YAG:Ce scintillation screen imaged by a CCD digital camera, was installed at the end of the 100 MeV Booster pre-injector together with a beam longitudinal structure monitor. This equipment plays an important role for the bunching system optimization and for the optical matching of the injection transfer line to the booster ring. Experimental results and comparison with multi-particle tracking codes simulation are presented in this paper.

INTRODUCTION

The Elettra new full energy Booster was commissioned and it is now in routinely operation at ELETTRA [1]. During the commissioning of the 100 MeV pre-injector linac [2], the TWISS functions and the normalized beam emittance was measured in order to match the optics with the transfer line. The used technique is the well-known quadrupole scan. Figure 1 shows a top view of the pre-injector to booster transfer line: the diagnostic station was installed at the end of straight-on line after the first transfer line bending magnet (beam is coming from the right side).

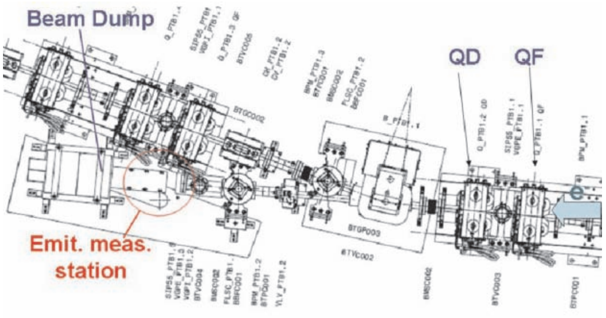

Figure 1: Top view of the emittance measurements set-up with the position of the beam diagnostic station and of the quadrupoles used in the measurement.

The diagnostic station is equipped with three types of screens: a YAG:Ce scintillation screen, an OTR and a CHROMOX ($Al_2O_3 : CrO_2$) screen, imaged by a CCD digital camera. To measure the emittance of the beam a quadrupole scan of the QF (for the x-plane) and QD (for the y-plane) was performed. Moreover a four electrode pick-up prototype, designed at DESY [3], is installed to detect the beam longitudinal structure. A global sketch of this equipment is shown in Figure 2 and readers are referred to [4] for more details.

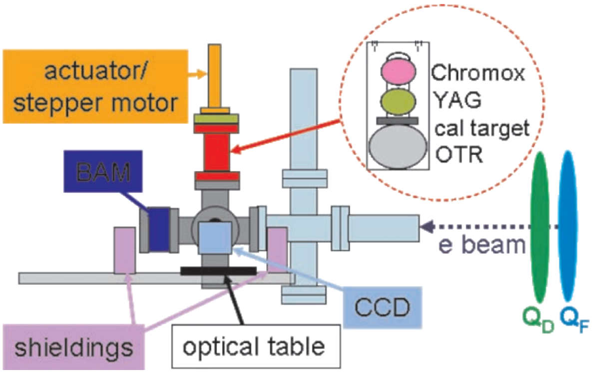

Figure 2: Schematic layout of the emittance measurement station.

BASICS OF EMITTANCE MEASUREMENT

The phase space coordinates $\mathbf{X} = \begin{pmatrix} x \\ x' \end{pmatrix}$ of a single particle are transformed through a beam transport channel **R** as

$$\mathbf{X}_f = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \mathbf{X}_i \qquad (1)$$

and similarly the Twiss vector $\mathbf{T} = \begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}$ becomes:

$$\mathbf{T}_f = \begin{pmatrix} R_{11}^2 & -2R_{11}R_{12} & R_{12}^2 \\ -R_{11}R_{21} & 2R_{12}R_{21} & -R_{12}R_{22} \\ R_{21}^2 & -2R_{21}R_{22} & R_{22}^2 \end{pmatrix} \mathbf{T}_i \qquad (2)$$

Defining **Q** the quadrupole transfer matrix and **S** the lattice transfer matrix up to the screen, the global transfer matrix **R** can be written as:

$$\mathbf{R} = \begin{pmatrix} S_{11} + S_{12} \cdot K & S_{12} \\ S_{21} + S_{22} \cdot K & S_{22} \end{pmatrix} \qquad (3)$$

where K is the quadrupole field strength. When the scan is performed on the quadrupole QD to measure the horizontal

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* giuseppe.penco@elettra.trieste.it

emittance, **S** is the transfer matrix of a drift, while when the scan is on the quadrupole QF, **S** becomes:

$$\mathbf{S} = \begin{pmatrix} 1 + K_{QD} \cdot D & \delta q + K_{QD}\delta q D + D \\ K_{QD} & K_{QD}\delta q + 1, \end{pmatrix} \qquad (4)$$

where K_{QD} is QD quadrupole strength, δq is the distance between QD and QF, D is the drift between QD and the screen. The mean square of the bunch transverse size is $\sigma^2 = \epsilon\beta$, where ϵ is the geometric emittance: after some calculation [5] σ^2 can be written as a quadratic function of K, with the coefficients as function of the Twiss parameters:

$$\begin{aligned} \sigma^2 \quad = \quad & \left(S_{11}^2 \epsilon\beta + 2S_{11}S_{12}(-\epsilon\alpha) + S_{12}^2(\epsilon\gamma)\right) \\ & + \left(2S_{11}S_{12}\epsilon\beta + 2S_{12}^2(-\epsilon\alpha)\right) K + S_{12}^2\epsilon\beta K^2 \end{aligned} \qquad (5)$$

Thus the optical functions and finally the geometric emittance is obtained by quadratic fitting the measured mean square of the beam size (σ^2) as function of the quadrupole field strength.

IMAGE PROCESSING

A great effort was spent in the images analysis, in order to obtain a reliable estimation of the σ of the bunch. Figure 3 shows a typical image acquired from the YAG screen.

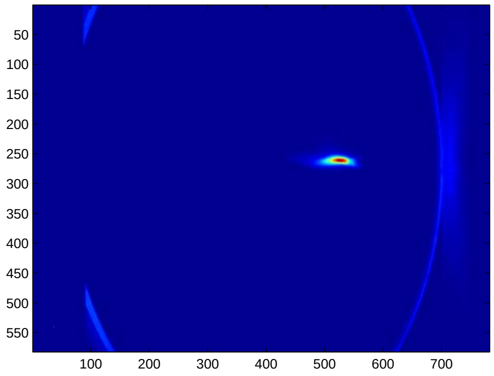

Figure 3: Image acquired from the YAG screen during a QD scan (vertical emittance measurement) in single bunch mode. Units in horizontal and vertical plane are the pixel number.

The processing of the data is based on fitting the data with a gaussian function $g(x) = H + C \exp\left(-\frac{(x-x0)^2}{2\sigma^2}\right)$, where H, C, $x0$, σ are the unknown parameters. The automatic data processing was developed in Matlab and it can be summarized as following:

- projection of the data in one plane, for example y-plane if the goal is to measure the vertical emittance,
- evaluate the median over three points to eliminate spikes,
- find an ansatz for the background H by applying a moving average to the data and finding the minimum,
- find an ansatz for the peak $x0$ as the maximum of a moving average,
- set $C = x0 - H$ as starting value for the fitting,
- find an ansatz for σ as $(V/\sqrt{2\pi})^{1/3}$, where V is the momentum of the data, for example y_i, defined as $V = \sum_i ((x_i - x0)^2 \cdot y_i)$,
- minimizing the distance between the "'ansatz"' function $g(x)$ and the data y_i in order to find the optimum set of unknown parameters H, C, $x0$, σ.

Figure 4 shows the result of this processing: reflections on the edges of the screen, visible in Figure 3, are removed and the gaussian curve $g(x)$ fits the experimental data very well.

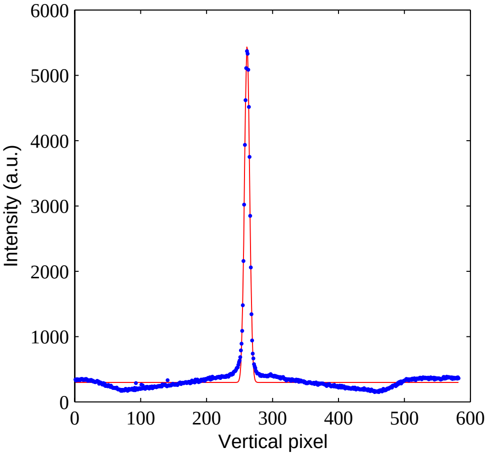

Figure 4: Projection on y-plane of the data relative to the image of Figure 3 (dot line) and fitting curve (solid red line).

SIMULATION RESULTS

Tracking code simulation performed during the Booster project design phase [6, 7] had taken in account the maximum charge expected by the filament (1.4nC) and the correspondent beam transport up to 100MeV. In simulations a pulse length of 2ns at the cathode was considered. In this condition only 50% of the charge can be transported up to 100MeV and the longitudinal structure at 3GHz presented one central bunch with high charge (about 360pC) and side bunches with low charge.

In this situation the normalized emittance at 90% (ϵ_{90}) was predicted to be about 70mm mrad. Booster requirements specified a single bunch charge of 50-150pC and a normalised ϵ_{90} of about 200 mm mrad at 100MeV [8], therefore simulation results had a safety margin.

In the present thermo-ionic gun it is possible to create sub-ns pulse but with a reduced charge, about 50pC that satisfies the Booster requirements, so that the beam can be bunched in one single peak.

EXPERIMENTAL RESULTS

Measurements were performed in single bunch mode, at 107MeV, varying the bunch charge from 50pC up to 150pC and optimizing the bunching system. The transport efficiency between the thermo-ionic filament and the diagnostic station is about 50% [4]. The beam emittance was first measured at low charge (50pC), setting the pre-injector parameters in order to have a single bunch at 100MeV. A scan on the quadrupole QD was performed, acquiring five images for each K values. The experimental data obtained and the quadratic fit are shown in Figure 5. The value of 11 mm mrad refers to the normalized RMS vertical emittance, which corresponds to 39% of the bunch particles in phase space if one assumes a gaussian distribution [9]. The emittance at 90% is 4.6 times larger than the RMS emittance, so we can estimate a normalized emittance at 90% of about 51 mm mrad. This value is in good agreement with the simulation.

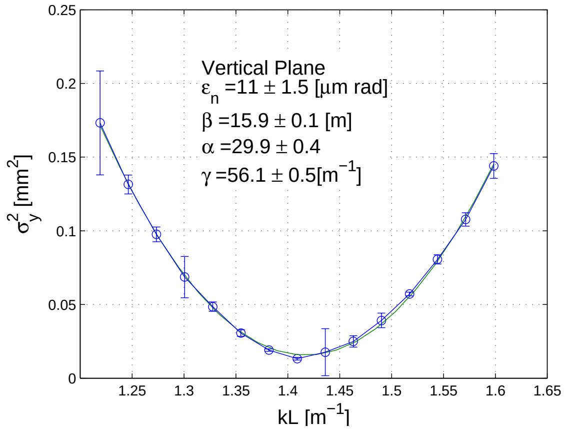

Figure 5: QD Quadrupole scan results for the RMS normalized vertical emittance measurements.

Similarly, a scan on the quadrupole QF was performed, providing a normalized RMS horizontal emittance of about 23 mm mrad ($\epsilon_{90} = 110mm\ mrad$), as shown in Figure 6. The error bars in the horizontal emittance measurements are due to fluctuation of the horizontal bunch size. The asymmetry between the two planes can be due to an asymmetry in the emission or to an horizontal misalignment of the pre-injector, which can introduce dipole components in the accelerating structures RF fields, leading to an horizontal emittance grow up. Further measurements at lower RF accelerating gradient are foreseen in the next future to investigate the source of this asymmetry.

Increasing the charge per bunch up to 150pC, as expected we obtained an increment of the normalized RMS emittance in both planes: $\epsilon_{RMS,y} = 17\mu rad$ ($\epsilon_{90,y} = 78\mu rad$) and $\epsilon_{RMS,x} = 31\mu rad$ ($\epsilon_{90,y} = 142\mu rad$).

CONCLUSION

An emittance measurement setup was installed in the straight-on beam line at the end of the ELETTRA booster pre-injector. An automatic quadrupole scan and beam profile acquisition have been developed, allowing the measurements of the optics parameters in real time. The measured values are in good agreement with the simulation and satisfy the Booster optics requirement.

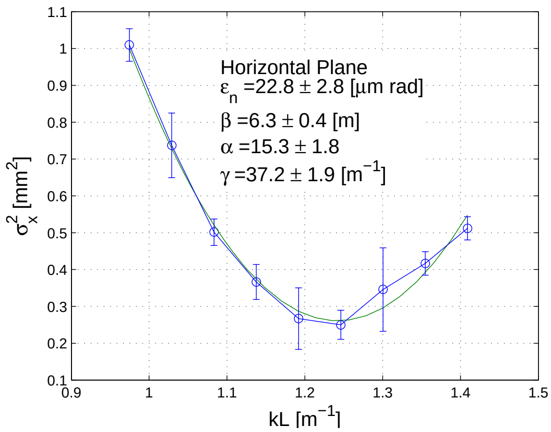

Figure 6: QF quadrupole scan results for the RMS horizontal emittance measurements.

REFERENCES

[1] M.Svandrlik, "Overview of the Status of the Elettra Booster Project", Proc. of this conference.

[2] G.D'Auria, "'Installation and Commissioning of the 100 MeV Preinjector Linac of the New Elettra Injector"', Proc. of this conference.

[3] K. Hacker, F. Loehl, H. Schlarb, "'Beam pickup designs suited for an optical sampling technique"', Proc of the FEL 2006 conference.

[4] S. Bassenese et al., "The Diagnostic Line of Elettra Booster 100MeV Pre-injector", Proc. of this conference.

[5] H. Wiedemann, "'Particle Accelerator Physics"', Vol.1, Springer.

[6] P. Craievich, S. Di Mitri and G. Penco, "'Beam Dynamics in the Pre-Injector and in the Injection Transfer Line of the ELETTRA Booster"', ST/M-TN-06/05, 2006.

[7] L.Picardi, C. Ronsivalle "'Design study of the first stage of the pre-injector linac for the ELETTRA new full energy injection system"', ENEA Technical Report RT/2007/ FIM /FIS/50l.

[8] Booster Conceptual Design Report, http://www.elettra.trieste.it/booster/CD/index.html

[9] M. Martini and H.Schonauer, CERN PS 97-18.