HIGH ENERGY EMITTANCE MEASUREMENT AT SPARC*

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Abstract

The characterization of the transverse phase space of electron beams with high charge density and high energy is a fundamental requirement for particle accelerator facilities. The knowledge of characteristics of the accelerated electron beam is of great importance for the successful development of the SPARC FEL, a R&D photo-injector facility for the production of high brightness electron beams to drive SASE and SEEDED FEL experiments in the visible and UV wavelength. Here high energy emittance measurements are discussed.

INTRODUCTION

In order to achieve the SPARC [1] goals a precise characterization of the beam phase space at high energy is needed. In this paper we present the results for both transverse and longitudinal emittance measurements, together with the slice emittance analysis. In particular we discuss systematic effects observed in the transverse emittance measurement with the quadrupole scan technique using two quadrupoles arranged as a doublet.

Typical operation energy is around 140 MeV. For this stage of commissioning we have operated with a photocathode driven laser pulse with gaussian longitudinal profile (6-8 ps FWHM). The bunch charge was around 200 pC. The laser spot on the cathode was around 300 μm rms. Downstream from the last accelerating section several tools for a full characterization of the beam parameters are installed (Fig. 1).

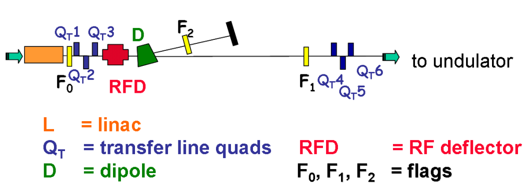

Figure 1: Layout of the high-energy experimental area.

TRANSVERSE EMITTANCE

The high energy transverse emittance measurement at SPARC is performed by means of a quadrupole scan [2] downstream from the third accelerating section. The transverse beam size is measured on the flag F_1 for different current values of quadrupoles Q_T1, Q_T2, Q_T3 (see Fig. 1); two quadrupoles have equal currents but opposite sign, and the third is used to control the beam spot shape. Quadrupoles are treated as thick lenses.

Typical Measurement

Usually, Q_T1 and Q_T3 are used with opposite polarity and Q_T2 is set at zero current, in order to reduce the overlapping of quadrupole fields. The transverse emittance is then determined by evaluating the Twiss parameters, $\beta\varepsilon$, $\alpha\varepsilon$ and $\gamma\varepsilon$, from the χ^2 minimization. The measured beam sizes, compared to the ones retrieved from the fit, are plotted in Fig. 2 as function of the quadrupole current.

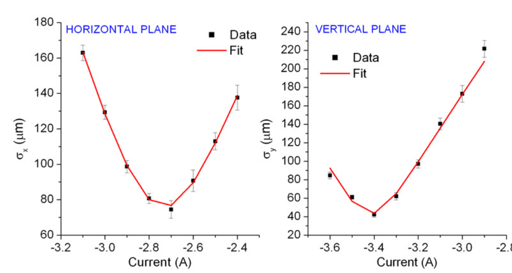

Figure 2: Comparison between the rms beam size measured at the flag F_1 (black squares) and the one retrieved from the χ^2 minimization (red curve) as function of the quadrupole current (125 pC, 140 MeV).

For a beam of 125 pC of charge and 140 MeV energy, the projected transverse emittance measured is $\varepsilon_{nx} = 1.52 \pm 0.05$ mm mrad and $\varepsilon_{ny} = 2.3 \pm 0.1$ mm mrad. The error on the emittance is estimated from the error propagation of the variance of the measurement error and accounts only for the statistical part. The high value of the projected emittance obtained with this charge is mainly due to inhomogeneities on the cathode surface.

Analysis of the Systematic Effects

The goodness of the least square fit on the experimental data is evaluated by backtracking the results in order to estimate the rms beam size on the flag F_0 at the end of the linac, where a comparison with a direct measurement can be performed.

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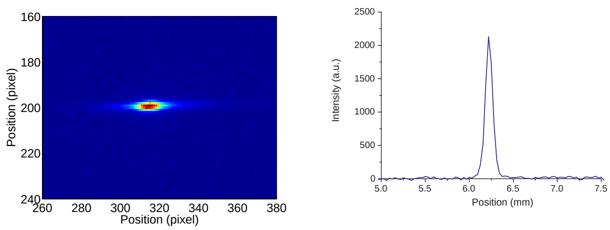
In the case considered in Fig. 2, the beam has a regular distribution as also shown from its projection (Fig. 3).

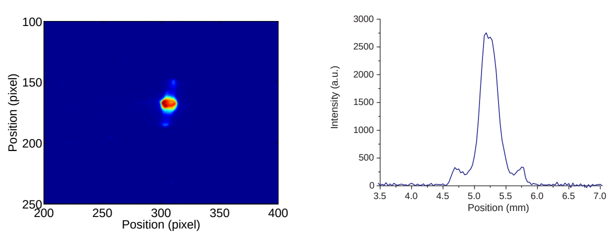


(a) (b)

Figure 3: Vertical (a) beam waist of a typical beam and its projection (b) as the one analysed for the emittance measurement. The pixel calibration is 31.25 μm/pixel.

It is then found that the agreement between the backtracked and the measured rms beam size at the end of the linac agrees within 3% in the horizontal and 7% in the vertical plane. The worse agreement in the vertical plane is also confirmed by the calculated reduced χ^2, 6 in the vertical plane with respect to 1 in the horizontal one.

Depending on the laser beam alignment on the cathode, the beam exhibited "side structures" due to strong disuniformities in the emission from the cathode (Fig. 4).



(a) (b)

Figure 4: Beam with side structures in a region close to the vertical waist (a) and its projection (b). The pixel calibration is 30.30 μm/pixel.

These tails behave differently changing the focusing strength: they overlap into the beam core in the waist and get further from it as the focusing power weakens. Fig. 5 shows the quadrupole scan in the vertical direction. Here the different behavior of the tails results in a "bump" close to the waist, where they are taken into account in the calculation of the rms beam size.

Two-quadrupoles Compared to One-quadrupole Scan

The main advantage in using two quadrupoles as a doublet in the emittance measurement is that, if the beam has a round shape, it preserves its symmetry during the scan and the emittance can be measured simultaneously in both planes. However, in order to observe a waist in both planes, the range of currents considered is wider, i.e. the focusing strength is stronger and the beam undergoes a stronger focalization.

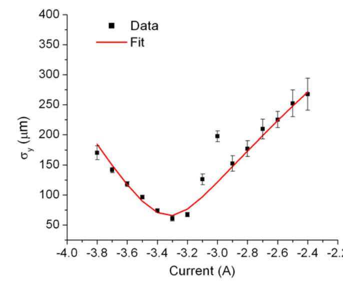


Figure 5: Quadrupole scan showing the effect of a beam with side structures (300 pC, 141 MeV).

At this regard a quadrupole scan with a single quadrupole has been done (Fig. 6 shows the horizontal plane) and the results have been compared to the scan with two quadrupoles (Fig. 7(a), black squares). These measurements have been done with a beam of 200 pC charge, 7 ps FWHM pulse length and 145 MeV energy.

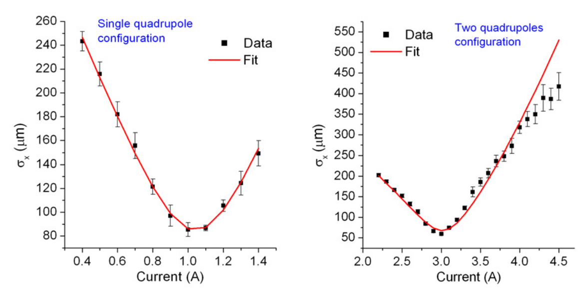
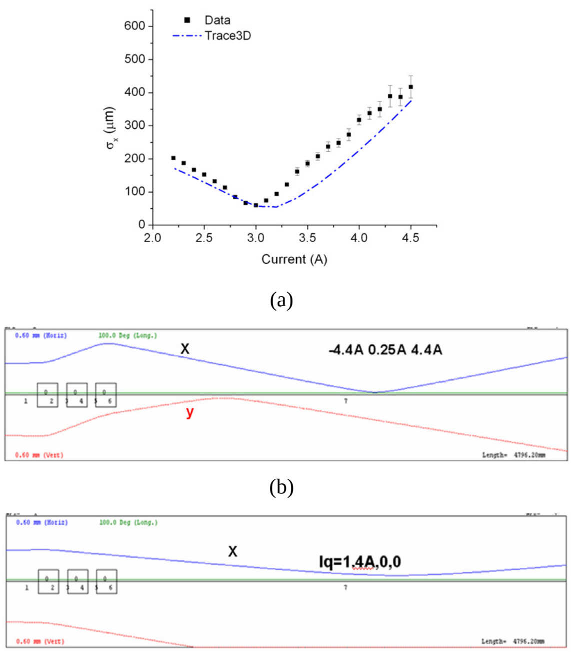


Figure 6: Quadrupole scan in single magnet and two magnets configuration. (200 pC, 7 ps FWHM pulse length and 145 MeV).

The Twiss parameters measured in the single quadrupole configuration have been then used as starting point for the TRACE3D simulation of the quadrupole scan with two quadrupoles. For the points before the waist, Fig. 7(a) shows a good agreement between measurements done in the single quadrupole and two quadrupoles configurations. After the beam waist, where the focusing strength is more intense, a non perfect agreement is observed. In the worst case, the emittance measured in the two quadrupoles configuration results to be about 30% higher than the one from single quadrupole scan.

Fig. 7, (b) and (c), shows how between the quadrupole triplet and the flag F_1, the beam, due to the higher focusing strengths, undergoes a more abrupt focalization in the two quadrupoles configuration with respect to the single quadrupole one, emphasizing those effects like chromaticity which depend on the quadrupole intensity. More systematic investigations on this comparison are needed.



(a)

(b)

(c)

Figure 7: (a) Two magnets quadrupole scan compared to a TRACE3D simulation. (b), (c) Trace 3D envelope in the two quadrupole and single quadrupole configuration, respectively. The y axis extends from 0 to 0.6 mm for both x and y envelope curve. 200 pC, 7 ps FWHM pulse length and 145 MeV.

SLICE EMITTANCE

The quadrupole scan technique, combined to the radiofrequency deflector (labeled as *RFD* in Fig. 1) [3], allows also the investigation of the beam slice emittance. By powering the RFD, the beam is vertically deflected and a quadrupole scan is performed only in the horizontal direction, with the constraint of keeping constant the vertical beam size over the whole scan. The vertical beam size with the RFD off, rescaled by the RFD calibration coefficient, defines the resolution of the measurement. In Fig. 8 the slice emittance measurement (blue dots) for the beam considered in Fig. 2 and a laser spot size on the cathode of 320x300 μm rms is compared with a PARMELA simulation performed assuming 150k particles, a rms thermal emittance ϵ_{th}=0.75 mm-mrad per radius (mm) and a slice length of 200μm.

LONGITUDINAL EMITTANCE

The SPARC RFD with deflection plane in the vertical direction, combined to the horizontal dispersive region represented by the dipole (labeled as *D* in Fig. 1), allows to measure the longitudinal trace space in a single shot [5]. A typical measurement at SPARC is shown in Fig. 9 and by means of a 2D image analysis the beam longitudinal emittance can be retrieved. In the actual working point of 1.5 MV in the RFD, the estimated longitudinal emittance is about 209 mm-keV in good agreement with the simulation.

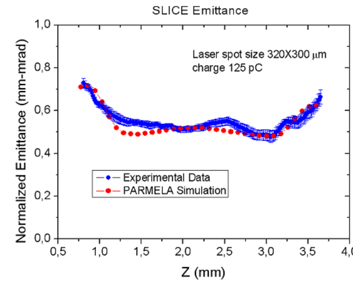


Figure 8: Slice emittance measurement compared to a PARMELA simulation. Z is the longitudinal position along the beam.

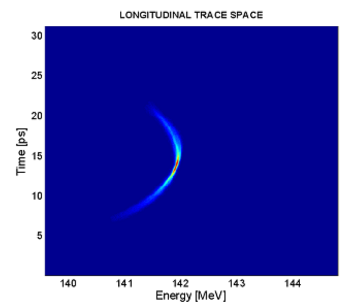


Figure 9: Longitudinal trace space at 140 MeV.

CONCLUSIONS

The tools for characterizing the 6D SPARC phase space at the end of the linac, where a 140 MeV energy is reached, have been completed. In the present operation we were limited by a strong transverse disuniformity on the cathode, which results in high values of transverse emittance. The goodness of the χ^2 test on the experimental data has been validated by the good agreement between the rms beam size measured at flag F_1 and the those retrieved by backtracking to the flag F_0. A preliminary comparison between the two quadrupoles and single quadrupole scan has been done. More investigations are planned.

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