PRELIMINARY CHARACTERIZATION OF THE BEAM PROPERTIES OF THE SPARC PHOTOINJECTOR

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Abstract

The SPARC photoinjector is the test prototype of the recently approved SPARX project. It is used as R&D facility to perform accurate beam dynamics studies, comparing measurements and simulations. The first results of beam characterization at full energy are presented.

INTRODUCTION

The SPARX project consists in an X-ray-FEL facility jointly supported by MIUR (Research Department of Italian Government), Regione Lazio, CNR, ENEA, INFN and Rome University Tor Vergata. The aim is the generation of electron beams characterized by ultra-high peak brightness at the energy of 1 and 2 GeV, for the first and the second phase respectively. The beam is expected to drive a single pass FEL experiment in the range of $13.5 \div 6$ nm and $6 \div 1.5$ nm, at 1 GeV and 2 GeV respectively, both in SASE and SEEDED FEL configurations. SPARX is the natural extension of the ongoing activities of the SPARC collaboration mainly focused on the SPARC photoinjector. It is a normal conducting linear accelerator hosted by INFN Frascati Laboratories that drives a FEL-SASE in the visible wavelength. The installation of the undulator modules is in progress and it will be finished for July this year. The commissioning of the Linac has been started delivering the beam at full energy of 150 MeV. Several and systematic studies are needed in order to achieve the design parameters. The preliminary results of the beam characterization are here reported as well as a description of the machine diagnostic.

SPARC LAYOUT

SPARC is a normal conducting accelerator. The RF gun is one of the most recent generation 1.6 cell S-band BNL/UCLA/SLAC type follow by 3 S-band travelling wave accelerator constant gradient structures. The power sources are the 45 MW peak, 2856 MHz klystron TH2128C. The Klystron n.1 feeds the the RF gun and the third accelerating structure with 4.5 μs RF pulses. Klystron n.2 feeds two high gradient accelerating sections through an energy compressor that allows to obtain 60 MW - 0.8 μs RF pulses. Around the first and the second accelerating structure several solenoids are placed to provide additional focusing both for velocity bunching [1] and to match the beam envelope with the linac according with the invariant envelope scheme [2]. The undulator [3] is composed by 6 sections of permanent magnet undulator, separated by 0.36 m gaps, and featuring single quadrupoles which focus the electron beam in the horizontal plane. Every module contains 75 periods each one 2.8 cm length, with an undulator parameter kw = 1.4. The FEL will operate in self amplified spontaneous emission (SASE) mode at a wavelength of about 500 nm with an expected saturation length of about 10-12 m. For this stage of commissioning we have operated with a laser pulse with gaussian longitudinal profile of FWHM in the order of 6-8 ps. The bunch charge was between 200 pC up to 700 pC, mainly limited by the low (in the lower order of 10^{-5}) and not constant quantum efficiency of the cathode.

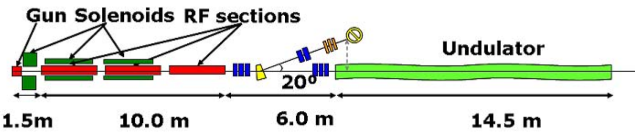

Figure 1: SPARC layout.

DIAGNOSTIC HARDWARE

The measurements of the beam transverse parameters is mainly a measurement of the beam rms size. So far we used mainly Ce:YAG radiator, while OTR metallic foils are installed and they will be used for high charge run (about 1 nC). The doping level of Cerium in the crystal is 0.18%. The response is linear up to 0.01 pC/μm^2 [4]. The radiation emitted in the forward direction from the Ce:YAG crystal is collected by a 45 degrees mirror downstream the radiator, on the same screen holder. We observe the back side of the transparent crystal radiator, thus minimizing the degradation of the spatial resolution due of the optics field depth. The small thickness of the crystal (100 μm) prevents appreciable blurring effects due to the crystal bulk emission, as well as significant multiple scattering.

Images are acquired using 8 bit digital CCD cameras (Basler 311f) equipped with 105 mm “macro” type objectives from SIGMA.

The beam envelope is measured in four different positions: one before the first accelerating module, 1181 mm

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far away from the cathode, two others positions are between the accelerating module, and the last at the exit of the third module.

Downstream the last section several diagnostic tools for a full characterization of the beam parameters are installed. A triplet of quadrupoles are installed, followed by the SPARC RF deflector [5], the dipole for the high energy measurement and the flags to evaluate the beam parameters (see Fig. 2). The quadrupoles are used both for quadrupole scan measurements and for the slice emittance measurements with the RF deflector on. The drift between the last quadrupole and the measuring flag is 3.9 m. Also the longitudinal phase space can be investigated using the RF deflector together with the spectrometer dipole.

The energy in the gun area is evaluated monitoring the displacement of the beam center changing the current in a steering coil. This coil has a high field quality and a field flatten for about 2 cm as reported in [6]. The lunch phase is set referring to the phase where the energy is maximum.

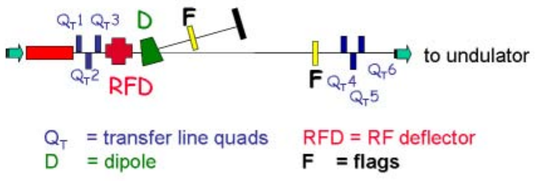

Figure 2: Layout of the experimental area at 150 MeV.

ENVELOPE MEASUREMENTS

To match the beam size into the linac and to control the emittance compensation process the envelope is measured in all the available flags. An example of a series of measurement is shown in Fig. 3 where are reported the rms transverse size in different position for several values of the gun solenoid.

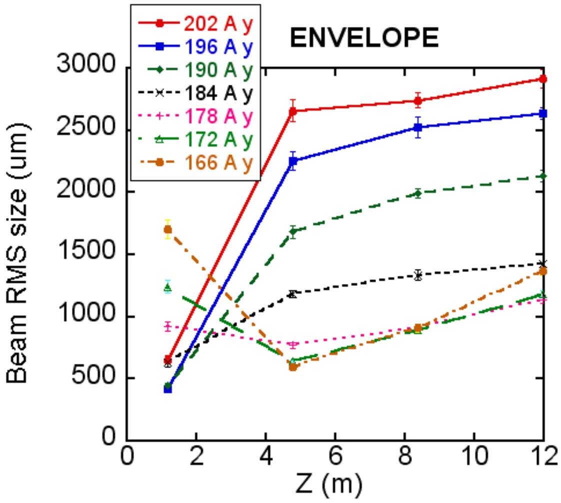

Figure 3: Envelope measurement along the linac.

The bunch length was 6.5 ps, with 340 pC of charge and a rms size on the virtual cathode of about 340 μm.

EMITTANCE MEASUREMENTS

Several measurements of emittance has been performed with the standard technique of quadrupole scan. The resolution of the optics is set in the order of 30 μm per pixel to have both large field of view and a reasonable number of samples for an accurate measurement of the beam size in the waist. A typical result of the quad scan is shown in Fig. 4.

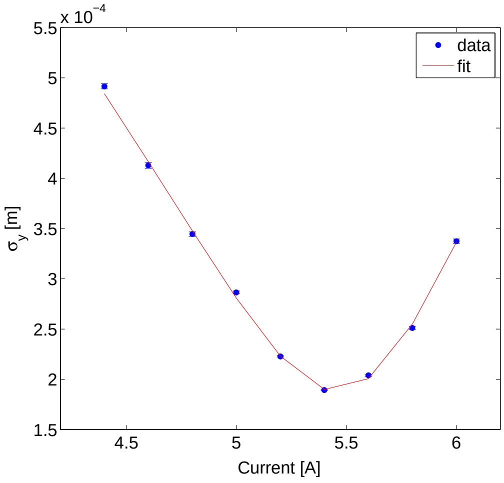

Figure 4: Fit of the data of the quadrupole scan.

In order to study the emittance compensation process and in particular the influence of the focusing solenoids on the traveling wave structures, a systematic analysis of the transverse emittance is important. In the Fig. 5 are reported the results of the first measurement. The charge was 500 pC with bunch length of 6.5 ps and a laser beam spot size of around 400 μm on the cathode.

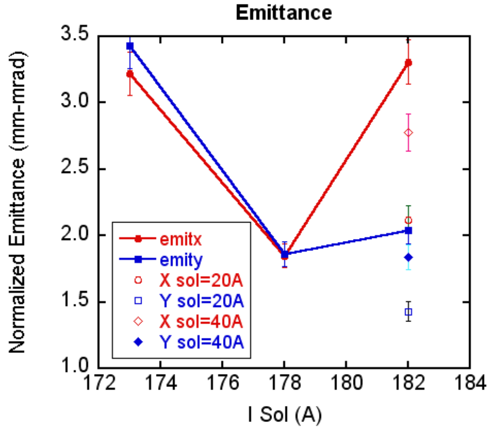

Figure 5: Emittance measurement for different configuration of the gun solenoid and the additional coils around the accelerating structures.

Cross checks of the data with the simulation are ongoing and are reported in [7]. Anyway the effect of the focusing solenoid on the value of the emittance is already visible in the Fig. 5.

Slice Emittance

A preliminary measurement of slice emittance has been performed. The bunch charge was 300 pC, 5.3 FHWM bunch length, with a beam energy of 145 MeV. The result is consistent with a measurement of the projected emittance that gives (2.8±0.1) mm-mrad.

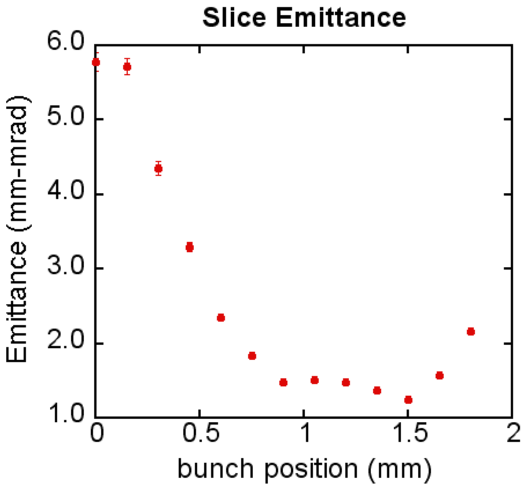

Figure 6: Slice emittance measurement.

Referring to Fig. 2 only the quadrupoles named QT2 and QT3 have been used together in order to maintain the vertical dimension (i.e. the longitudinal resolution) constant during the scan. The slice length has been set to 150 μ i.e. about 0.5 ps. More details can be found in [8].

BUNCH LENGTH MEASUREMENTS

The evaluation of the bunch length is mandatory especially in the foreseen studies of the velocity bunching. The RF deflector is used for this task. The ultimate temporal resolution is affected not only from the deflecting voltage but also from the intrinsic vertical dimension of the beam size at the flag when the deflector is off. In the actual condition the temporal resolution is estimated to be around 1 ps.

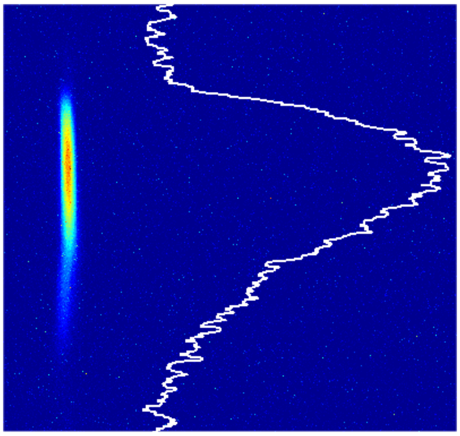

Figure 7: Bunch length measurement.

In Fig. 7 a measurement with 300 pC charge is reported, giving a length of 7.7 ps FWHM equal to 5.5 mm on the flag.

Longitudinal Phase Space

Using the RF deflector and the spectrometer dipole is possible to study the longitudinal phase space.

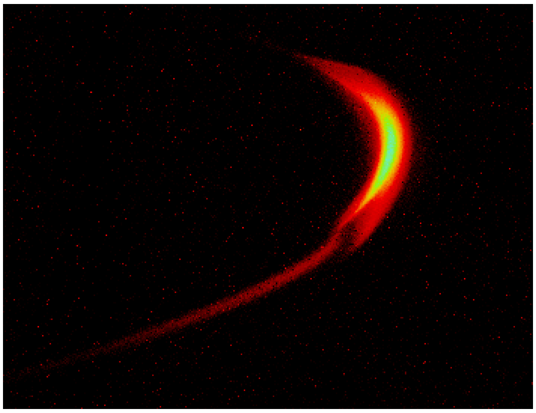

Figure 8: An example of the longitudinal phase space.

An example of non perfect optimized beam is shown in Fig. 8.

CONCLUSION

The SPARC commissioning has begun. In this early stage the beam has been delivered to the end of the linac at the nominal energy of 150 MeV. All the diagnostic and the analysis tools have been tested and commissioned. Preliminary beam characterization has been done with a lower charge, due to reduced and variable cathode emissivity.

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