CHARACTERIZATION OF THE SPARC PHOTO-INJECTOR WITH THE MOVABLE EMITTANCE METER*

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Abstract

As a first stage of the commissioning of SPARC accelerator a complete characterization of the photo-injector is planned. The objective is the optimization of the RF-gun setting that best matches the design working point and, generally, a detailed study of the emittance compensation process providing the optimal value of emittance at the end of the linac. For this purpose a novel beam diagnostic, the emittance-meter, consisting of a movable emittance measurement system, was conceived and built. This paper presents the results of the first measurements with the emittance-meter showing the characteristics and the performance at the SPARC photo-injector.

INTRODUCTION

The aim of the SPARC [1] project is to promote R&D towards high brightness photo-injectors to drive a SASE-FEL experiment. The 150 MeV SPARC photo-injector consists of a 1.6 cell RF gun operated at S-band (2.856 GHz, of the BNL/UCLA/SLAC type) and high-peak field on the cathode incorporated metallic photo-cathode of 120 MV/m, generating a 5.6 MeV, 100 A (1 nC, 10 ps) beam.

The beam is then focused and matched into 3 SLAC-type accelerating sections, which boost its energy to 150-200 MeV. The first phase of the SPARC Project was dedicated to the beam RMS emittance measure along the drift space following the RF gun, where the emittance compensation process occurs.

The complete characterization of the beam parameters at different distances from the cathode is important to find the injector settings optimizing emittance compensation and for code validation. For this measurement, a dedicated moveable (in z, z being the distance from the cathode, measured along the accelerator axis) emittance measurement device (emittance-meter) is used allowing to measure the RMS emittance in the range from about z=86 cm to z=210 cm. More than a simple improvement over conventional, though non-trivial, beam diagnostic tools this device defines a new strategy for the characterization of novel high performance photo-injectors, providing a tool for detailed analysis of the beam dynamics and the phase space.

The technique to measure the beam emittance and the phase space, in both the horizontal and vertical planes, makes use of a double system of horizontal and vertical slit masks [2]. Each mask consists of a slit array (7 slits, 50 μm width spaced of 500 μm, 2 mm thick) and two single slits, 50 and 100 μm width. The slits are realized by photo-chemical etching providing, compared to mechanical machining, higher precision and improved smoothness of slits edges. The multislits are used for single shot measurements, provided the beam size is large enough for an adequate beam sampling by the slit array. Alternatively, a single slit can be moved across the beam spot. In this case the accuracy of transverse sampling can be freely chosen adjusting the step between the different positions of the slit. This measurement is an integration over many pulses.

Linear actuators with stepper motors are used to control the insertion of the slits masks into the beamline. A differential encoder and a reference end switch guarantee reproducibility and accuracy of the movement to better than 2 μm, required for single-slit multi-shots measurements.

The projected cross-section of beamlets emerging from the slit-mask are measured by means of a downstream Ce:YAG radiator [3]. Because beam size and divergence depend on the device longitudinal position, the slit to screen distance must be properly adjusted in order to optimize the accuracy of the beamlet profiles measurement. A bellow is therefore interposed between the slit mask and the screen, allowing their relative distance to be changed from 22 to 42 cm, to optimize the drift in order to fit several scenarios (converging beam, diverging beam, single or multi-slits). Refer to Fig.1 for a schematic drawing of the emittance meter.

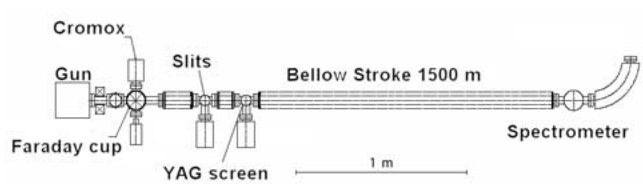

Figure 1: Schematic drawing of the e-meter

Radiation emitted in the forward direction from the Ce:YAG crystal is collected by a 45 degrees mirror downstream from the radiator. The back face of the transparent crystal radiator is observed, thus minimizing degradation of the spatial resolution due to the depth of field of the optics.

Images are acquired using digital CCD cameras (Basler 311f) equipped with simple 105mm "macro" type objective

* This work has been partially supported by the EU Commission in the sixth framework program, contract no. 011935 EUROFEL-DS1.
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from SIGMA. The magnification of 0.66 gives a calibration of 15.4 μm per pixel.

Such cameras offer the advantage that the signal is digitalized directly by on-board electronic so that there is no need for a frame grabber and the output signal, being digital, is less sensitive to environmental noise. Furthermore, the IEEE1394 (firewire) link allows simpler cabling topology because it carries both pixels readout and commands to the camera. Charge is measured by means of a Faraday cup, placed in a cross together with a cromox screen to image the beam at 60 cm from the cathode. This screen is also used to monitor the position of the laser spot on the cathode. The emittance-meter is followed by a magnetic spectrometer measuring the beam energy and energy spread

TRANSVERSE PLANE MEASURE

We performed a detailed characterization of the photo-injector, studying the beam dynamics as function of relevant parameters such as the solenoid field, the beam charge and size, the laser pulse length and its shape. Refer to [4] for more details.

Beam Envelope measure

Evolution of the bunch transverse size along the photo-injector is a important, although simple, measurement we performed with the emittance-meter. It takes less than 5 minutes to complete the measurement that consists of continuously changing the z-position of the movable part between the upper and lower ends, grabbing beam images at every position. These images are on-line processed to filter out the background noise and to calculate the RMS value of the beam size. In Fig.2 are shown results of measurements of the RMS beam size vs z for different values of the solenoid field.

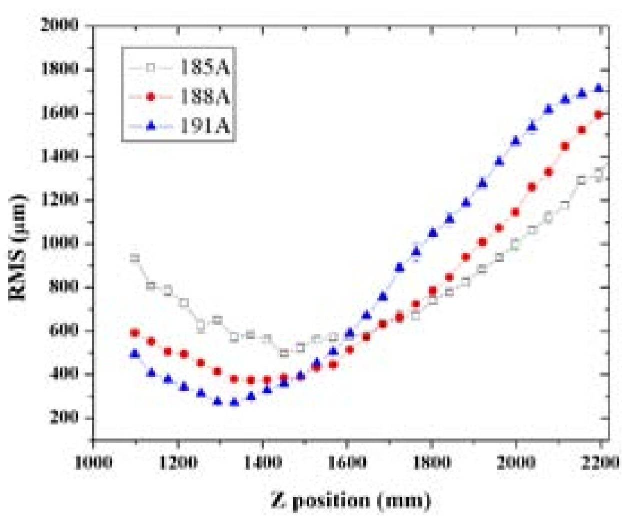

Figure 2: Envelope of the beam with different solenoid currents

The different curves show that the position of the beam envelope waist and its value are changed as consequence of the different solenoid currents. With this system we can easily identify the solenoid value that gives the waist in the expected z position.

Emittance measurements

The emittance is measured, for both x and y both planes, at different positions along the emittance-meter. As consequence of emittance compensation process, the beam size and divergence change along the photo-injector: the beam is converging at the beginning of the emittance-meter and diverging in the second half. The transverse dimension depends on several factors but, usually, we obtained a beam with RMS size ranging from 1.5 mm down to 200 μm.

Single vs multi-slits

Usually, when the beam is close to the waist and the beam size is small the multi-slits mask is not convenient because it produces a limited number of beamlets. The multi-slits mask is not used also in the region close to the end of the emittance-meter where the beam size is larger than the part of the mask covered by the slit-array. In all of the others conditions the multi-slits mask provides fast single-shot measurements, while we use the single-slit for accurate analysis.

It's worth to mention that results produced by single-slit or multi-slit measurement, with the same beam conditions, have always been fully consistent. In addition we compare the RMS beam size at the slit-mask (measured by moving the screen at the slits position) against the value of beam size estimated by the algorithm we use to calculate the emittance. We always obtained an excellent agreement between the results. While for the multislits the sampling rate is fixed by the slits distance (500 μm) with a single slit we can change it depending of the beam size. Typical values of the sampling distance between the slit positions ranges from 110 μm to 380 μm At least nine beamlets are always collected with the single slit.

Emittance calculation and phase space tracing

With the emittance meter is possible to follow the emittance evolution, and tuning the machine parameters. Fig. 3 shows an emittance behaviour at 200 pC, measured before the laser cleaning of the cathode, when the quantum efficiency at the cathode was not uniform.

A typical emittance measurement with the single-slit mask consists of collecting 15 beam images for each slit position. The center of mass and RMS size of beamlets are then calculated for each image and averaged. We verified that a larger statistic doesn't significantly improve the accuracy of results. From the beamlets images we calculate the projection on the axis, subtract the baseline, try a gaussian fit to find the best position for the distribution center, reduce the number of the relevant points skipping these that are outside the 3 standard deviation from the centre and only on the remaining points we calculate the RMS parameters.

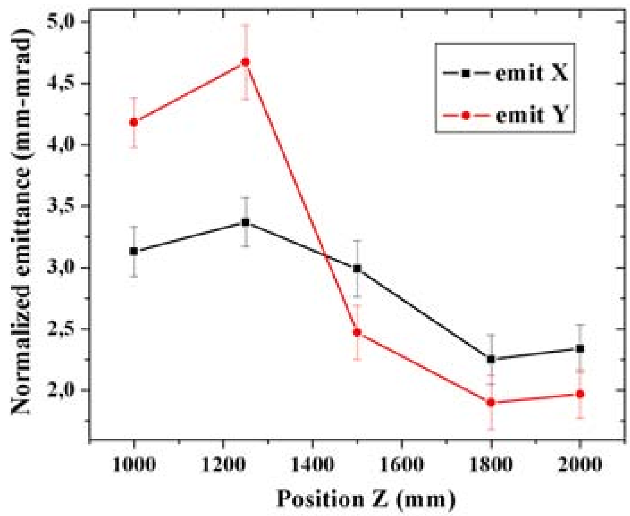

Figure 3: Emittance measurements along the e-meter

The use of big magnification, an high efficiency YAG and a CCD with a gain remotely controlled give a good signal to noise ratio and large number of sampling point for every beamlet in all the conditions.

The 1-D pepper pot technique allows not only to measure the beam and the Twiss parameters, but also to reconstruct the phase space [5]. Here in Fig.4 the phase space reconstruction in different positions, measured at low charge, 100 pC.

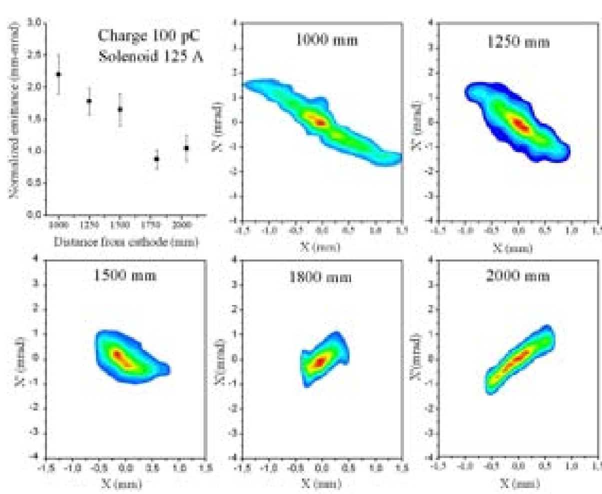

Figure 4: Phase space measure along the e-meter

LONGITUDINAL PLANE MEASURE

The e-meter gives also the possibility to investigate the longitudinal dynamics.

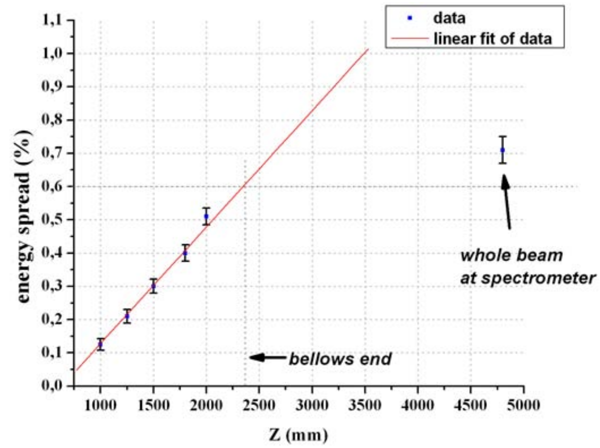

Figure 5: Energy spread vs longitudinal position

Moving the slit over the beam and measuring the energy and the energy spread in the spectrometer gives information of possible correlation between position and energy. Also centering the slit on the beam and moving along the emittance meter allows the measure of the energy spread in different longitudinal positions. The energy spread is frozen at the point where the beam is cut. Measuring it at the spectrometer, moving that position, gives the graph in Fig 5.

While the contribution at the energy spread from the longitudinal space charge is always present, the wake fields of the bellow affects the spread only till its end.

CONCLUSION

The SPARC emittance meter gives the possibility to measure the beam parameters a different distances from the cathode, giving information on the transversal and longitudinal phase space. The improvement on the laser parameters, the change in the solenoids field, the modification in the solenoids alignment can be easily and fast checked. Also the possibility to have several measures along the beam line gives a better understanding of the dynamics and easier comparison with the simulations.

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