DESIGN STUDY OF A MOVABLE EMITTANCE METER DEVICE FOR THE SPARC PHOTOINJECTOR

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Abstract

Preliminary studies of the SPARC RF-Gun are planned to obtain an accurate analysis and optimization of the emittance compensation scheme, measuring the beam emittance evolution downstream the RF-Gun with an appropriate diagnostic system. Since in a space charge dominated beam the use of the quad-scan method is not applicable a 1D pepper-pot method will be used instead. A metallic mask with narrow slits will be installed on a longitudinally movable support, spanning a 1.5 m long region, to measure the emittance in several positions and reconstruct its evolution in the post gun section. Numerical simulations of the measurement, mainly based on PARMELA, have been used to estimate the achievable accuracy and to optimize the experimental setup. Wake field effects induced by the beam propagation through the long bellows have been also investigated with HOMDYN. Based on these simulations the design of the apparatus, called emittance-meter, has been realized and is under construction at LNF.

INTRODUCTION

The aim of the SPARC project is to promote an R&D activity to develop a high brightness photo-injector suited to drive a SASE-FEL experiment.

The first phase of the SPARC Project foresees the systematic emittance measurement along the post-RF gun drift where the emittance compensation process occurs. The complete characterization of the beam parameters at different distances from the cathode is important for code validation and to place the first accelerator module in the best position according to the emittance compensation scheme.

For this measurement a dedicated movable (in z) emittance measurement tool will be used giving the possibility to perform measurements from about z=83 cm to z=233 cm (the cathode is at z=0). The technique that will be employed for the emittance measurement consists in the use of a double system of emittance slit-arrays, horizontal and vertical, to measure the emittance and the Twiss parameters in both planes.

Numerical simulations of measurement based on this apparatus, mainly using ad-hoc simulation codes and PARMELA beam dynamics calculation, have been done [2] in order to optimize the mechanical design and the overall system performances.

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THE EMITTANCE-METER

General Layout

The technique that will be employed for the emittance measurement consists in selecting one or several beamlets by means of an intercepting multi-slit mask (fig.1) or a single slit moving transversally over the beam spot.

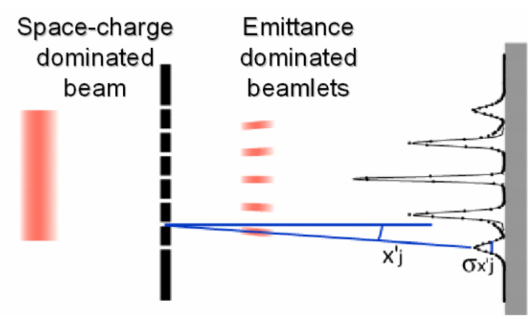

Figure 1: Multi-slits mask intercepting a space charge dominated beam.

The slits reduce the dominated space charge incoming beam into some emittance-dominated beamlets that drift up to an intercepting screen. If the screen response is linear, the intensity of beamlets spots on the screen are directly proportional to the number of particles in the beamlets which hit the screen and the rms un-normalized emittance value can be retrieved by the formula [1].

The slits mask must stop, or largely degrade, the intercepted components of the beam. High-Z material, 2 mm thick tungsten in our case, will be used. The design of the apparatus is sketched in Fig.2. Two 1.5 m long bellows allow the cross, housing the slits mask, to be moved along a region where the most relevant part of the emittance compensation process occurs.

The measurement conditions change at different longitudinal positions, as consequence the distance between the slits mask and the analyzing screen cannot be fixed. For instance, when the value of the Twiss parameter α is close to zero (beam is highly collimated) a long drift is needed to produce a noticeable difference in the beamlets size respect to the slits width. On the opposite when the beam is strongly diverging a long drift is unadvisable because the beamlets spread on a large area. In this case the possible beamlets overlapping and the lower signal-to-noise ratio might reduce the accuracy of the measurement. For this reason another bellow is foreseen between the slits mask and the screen, allowing changing their distance from 20 to 40 cm, a measure that the simulations demonstrated to be a good compromise for the different scenarios.

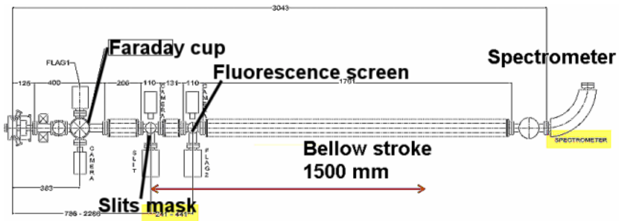

Figure 2: Emittance-meter design.

The beam will be spent in a dump after a bending magnet. Before the dump, beam energy and energy spread will be measured.

Slits Mask

Two slit masks, mounted on two independent holders 90º with respect to each other, will be used to measure the emittance in the horizontal and vertical planes. A 2 mm thick tungsten mask was considered as sufficient to completely stop the 5.6 MeV electron beam. The slits width will be 50 µm, being it a compromise between the requirement to produce emittance dominated beamlets, so the space charge contribution is negligible after the mask, and the practical requirement to have still enough electrons for the sensitivity of the analysis system. PAMELA code was run with 450K particles to check the influence of the residual space charge and, as evident from Fig.3, the contribution is negligible.

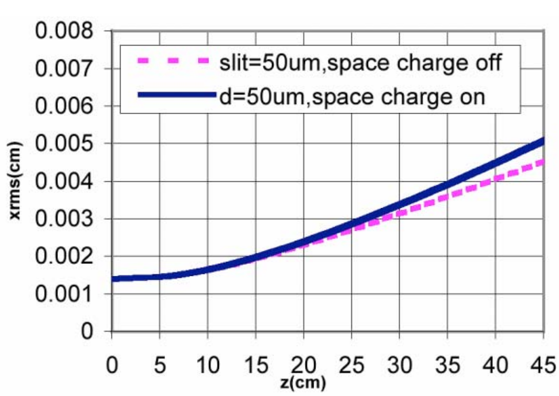

Figure 3: Analysis of the residual space charge effect after the metallic mask.

Every single slits are realized precisely machining a tungsten piece, and removing in the central part 50 µm of metal. Then the parts are stacked to build the multi-slits mask (see Fig.4) and two single slits mask 50 µm and 100 µm respectively. A prototype of the pepper-pot has been realized to verify the achievable machining accuracy for this design. In the first set of slits produced, 8 over 9 shown machining accuracy better than 10%, thus compatible with the needed tolerances. Since the multi-slits masks are made assembling single metallic parts, they will be built selecting the best slits among those being produced. It is worth to mention that the precise values of the slit widths will be included into the analysis formula avoiding systematic errors in the evaluation of the beam emittance.

In the slits-array the distance between slits is 500 µm providing an adequate transverse sampling of the beam and compatibility with machining tools. The main advantage of a multi-slits mask is the possibility to have single-shot measurements, thus not affected by possible shot-to-shot beam fluctuations.

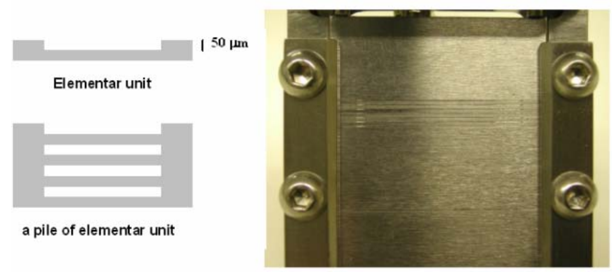

Figure 4: Slit mask design.

In spite of that, the multi-slits system might not be suited in such conditions where the beam is well focused and highly collimated, i.e. in the proximity of a beam waist, because the number of beamlets emerging form the multi-slit mask might not be sufficient for a good reconstruction of the phase space, as illustrated in Fig.5.

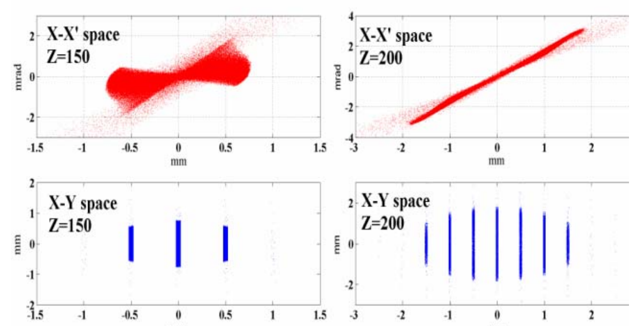

Figure 5: Phase space and multi-slit option for different scenario.

In this case we'll use a single slit to transversally scan the beam collecting together the image from different positions. In this case the measurement is not single shot and beam fluctuations must be taken into account.

The thickness (z-direction) of the slits defines the angular acceptance of the mask, i.e. the maximum divergence allowed for particle trajectories selected from the mask. As consequence, this value cannot be lower than the beam angular divergence otherwise the particles will be also selected because of their divergence and not just because their transverse position. Following a detailed analysis by simulations we decided to design the mechanical support in such a way to allow tilting of the metallic mask in order to optimize the mask vertical angle with respect to the beam before the measurements.

Screens and Image Acquisition

Two main requirement must be fulfilled by the radiator screen: it needs to have a linear response with beam charge in the range of few tenths of pC and it must guarantee a resolution better than 20 µm. Although OTR (Optical Transition Radiation) radiators, like aluminum foils, provide both high resolution and perfect linear response they have the disadvantage of a low intensity radiation. For our application, possible alternatives are Ce:YAG radiators and fluorescent material like BeO, that we are currently testing in the DAFNE Beam Test Facility.

For the image acquisition we'll use digital CCD cameras. They offer the advantage that the signal is digitalized directly from the camera electronics and there is no need of frame grabber, as result the outgoing signal, being it digital, will not be disturbed by the environmental noise, Furthermore the IEEE1394 (firewire) link allows simpler cabling topology because it carries both pixels readout and commands to the camera. A simple "macro" type objective will be used as imaging system.

Bellows

The influence on the beam quality of the 1.5 m long bellow has been investigated [3]. Wake fields perturbations due to the corrugated structure, especially when beam will not be well-aligned on-axis, were studied using HOMYDIN code and the wake fields were computed with the diffractive model Bane Sands.

The graph in Fig.6 shows the variation in percent of the beam emittance (at position z=150 cm from the cathode) due to a bellow misalignment for different values of the beam transverse position with respect to the bellow axis. In the worst case of 1 mm misalignment the contribution of the wakes to the emittance degradation is lower than 2%, thus practically negligible.

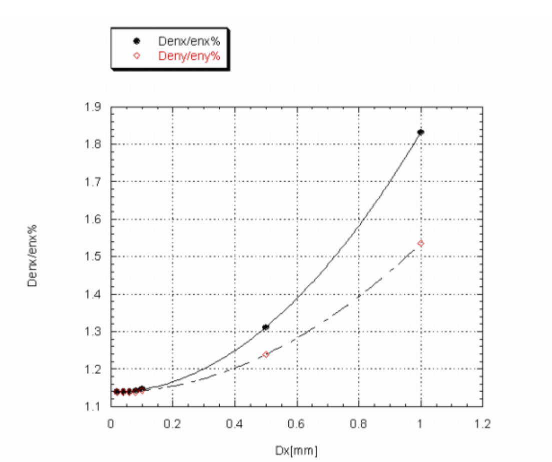

Figure 6: Degradation of the emittance due to a possible bellow misalignment.

The increasing of the energy spread due to the beam flight through the long bellows is analyzed in the plot of Figure 7. As for the emittance, the degradation of the beam has not practical relevance.

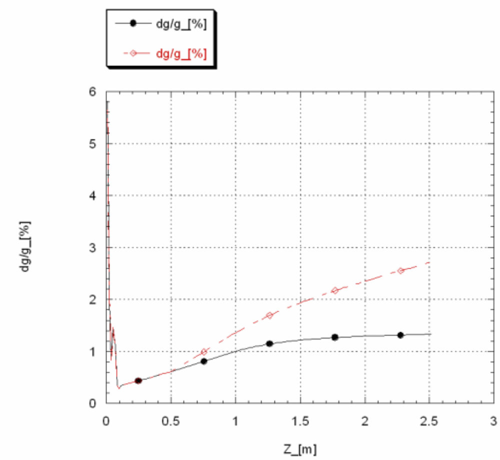

Figure 7: Energy spread vs z with (red curve) and without bellow.

CONCLUSION

The SPARC Emittance-meter will be built to perform a detailed study of the emittance compensation process in the SPARC photo-injector and to optimize the RF-gun and the accelerator working point. Installing the measurement system, based on the so-called "pepper-pot" method, between two long bellows we will have the possibility to scan a region 1.5 m long downstream the RF-gun.

Simulation codes have been used to study the layout and the mechanical design of the apparatus. Mask thickness, slits width, drift length between mask and screen, single slit vs. multi-slits option, alignment errors etc. have been studied to optimize the design and evaluate the performance of the system.

A prototype of the metallic mask has been already realized and measured. The overall apparatus design has been completed and the components are under construction at the LNF to be finally assembled by the end of 2004.

Acknowledgements

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