COMMISSIONING OF THE SPARC MOVABLE EMITTANCE METER AND ITS FIRST OPERATION AT PITZ

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Abstract

For the SPARC Project a novel diagnostic device, called "Emittance-meter", has been conceived and constructed 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. It consists of a movable emittance measurement system, based on the 1D pepper-pot method, installed between two long bellows with the possibility to scan a region 1.2 m long downstream the RF-gun. The construction of the device was completed in the first part of this year and a series of laboratory tests, to evaluate its performances, were carried out in Spring 2005. At the beginning of the summer the complete system was moved to DESY at Zeuthen to be installed on the Photo Injector Test Facility PITZ. After the commissioning it will be used for measurements of the PITZ electron beam in the framework of collaboration between the SPARC and PITZ Projects aiming on studies and operations with photo injectors.

INTRODUCTION

The “SPARC emittance meter” (“SPARC e-meter” shortly) is a diagnostic device designed for a detailed analysis of the beam dynamics in the region of the SPARC injector where a significant evolution of transverse emittance occurs [1].

Design of SPARC e-meter has been optimized with respect to the design parameters of the SPARC electron beam, namely energy, nominal transverse emittance and size, charge per bunch etc. [2].

The construction of the device was completed in the first part of this year while the beam studies of SPARC Injector with the e-meter are scheduled for the end of 2005.

The evidence of a temporal gap between the completion of the e-meter and its first scheduled operations at SPARC suggested the possibility of a temporary installation at DESY Zeuthen for a round of measurements of the PITZ electron beam in the framework of a collaboration aiming on studies and operations with photo injectors.

To permit the installation of the SPARC e-meter at PITZ we modified the original design of the system to ensure its mechanical compatibility.

Before its shipment to DESY Zeuthen a number of test of the e-meter have been carried out to verify its performance and calibrate the components.

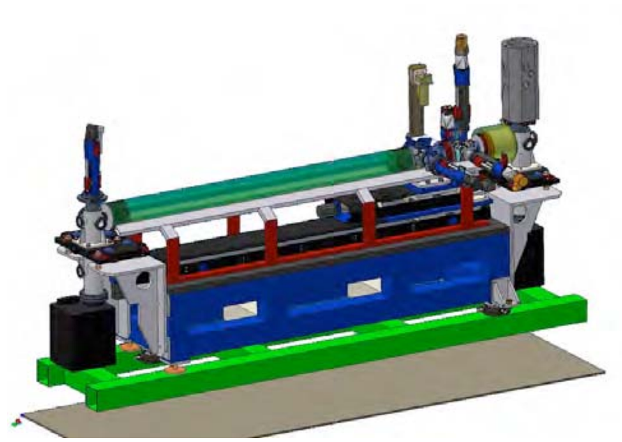

Figure 1. 3D mechanical drawing of the SPARC e-meter. In this drawing are also included one of the two alignment tools, to be installed during alignment on top of the end flanges (grey cylinders), and the PITZ girder (green structure).

TESTS AND EVALUATION OF PERFORMANCE

Slits Mask

For the measurement of the emittance in the horizontal and vertical planes using the *1D pepper-pot method* we have two slit masks, mounted on two independent holders 90º with respect to each other. Each slits mask is assembled stacking single pieces made of 2 mm thick tungsten with a well defined profile. Once assembled these pieces form a mask with, in the upper part, two single slits 50µm and 100µm respectively and, in the lower part, an array of 7x50 µm slits separated by 500µm.

The single slits will be used for multi-shot measurements, scanning transversally the beam and collecting together the images from different positions.

In 2004 a first prototype of slits mask has been realized precisely machining a tungsten piece, and removing in the central part 50 μm, or 100 μm, of metal. A preliminary analysis using a profile projector showed that agreement of average measured widths, with respect to the nominal value, was better than 5µm for 7 over 9 of the slits produced, thus compatible with the needed tolerances.

Nevertheless, a more accurate analysis with an optical microscope evidenced that while the average width was within the tolerances, irregularities of the profile due to roughness of edges might locally exceed, in some cases, 10% of the nominal width.

An alternative method for the preparation of slits we investigated is photo-chemical machining. Optical analysis of slits produced using this method showed higher uniformity of the slits and improved smoothness of edges consequence of the more precise etching process. It also eliminates irregularities produced by machining, due to the mechanical stress of material (Fig.2).

Screens and imaging system

The transverse distribution of low-charge beamlets emerging from the slit-mask needs to be measured with high accuracy.

It means that radiator screens, used for this purpose, need to have a linear response with beam charge in the range of few tenths of pC and they must guarantee a spatial resolution better than 20 µm.

Same performance are required from the imaging system that should not introduce any degradation to the figure above.

Doped-YAG radiators, either crystals or sintered screens, are good candidates because of their high resolution and efficiency.

For our application, we focused our attention on Ce:YAG radiators that we tested at the DAFNE Beam Test Facility.

We collect forward radiation emitted from Ce:YAG crystal with a mirror at 45° downstream the radiator. As result the radiator is observed at 90° with respect to the rear face thus minimizing the degradation of spatial resolution due to the non-negligible thickness of transparent crystal.

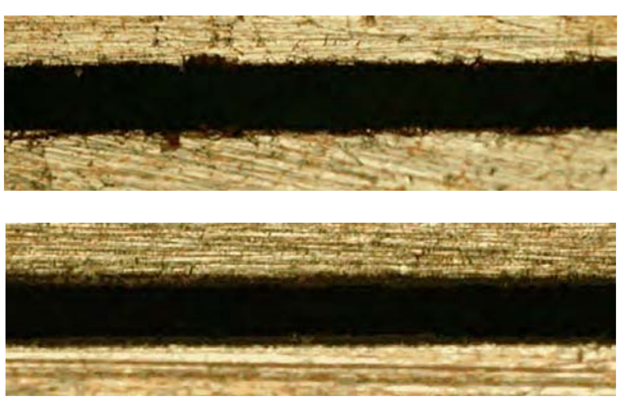

Figure 2. Optical microscope pictures of the single-slit obtained by mechanical machining (top) compared to single-slit produced by photo-chemical machining (bottom).

The performance of the Ce:YAG radiator has been compared to those of a Cr-oxide radiator used by our group in previous applications.

Both radiators have been installed at the same diagnostic station in the DAFNE Beam Test Facility and their performances measured under different beam conditions, within the range of values expected in the SPARC injector.

Analysis of results shows that performances of the Ce:YAG screen are superior: efficiency is a factor 2-3 higher than Cr-oxide and resolution is evidently better, as we can observe comparing the two pictures on Fig.3. At the same time we didn't report any evidence of a deviation from a linear correlation between the light yield from the two radiators varying the charge density of the beam in the range of values expected in the SPARC injector. This confirms a good linearity of the Ce:YAG radiator with charge density in the range of values of interest.

Imaging system includes a digital CCD cameras (Basler 311f) and a 105mm "macro" type objective from SIGMA. In the current set-up, the magnification, and the correspondent resolution, has been chosen to better adapt to the PITZ beam size. Being the distance of CCD from the object (the radiator surface) 300 mm, we calculated a magnification of 1:1.7 and the resolution of the optical system has been measured to be 17,2 µm (Fig.4). It's worth to mention that tests of the imaging system previously made in our laboratory shown that a resolution better than 11 µm can be achieved.

The digital cameras are connected to the e-meter control system by means of their built-in firewire (IEEE1394) interface that can be used for both images read-out and control of the camera settings.

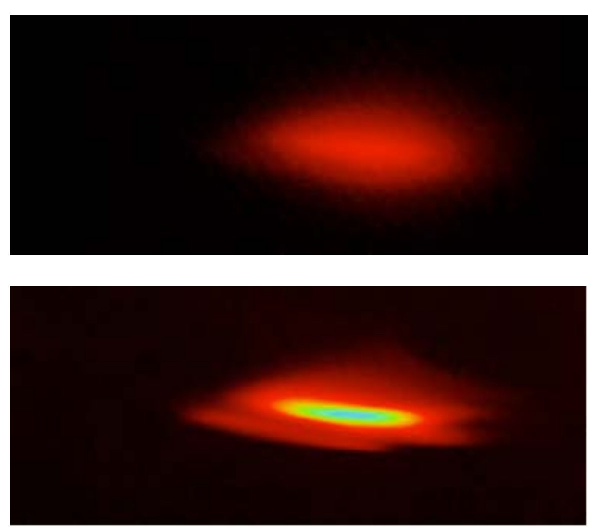

Figure 3. Electron beam imaging using Cr-oxide (top) and Ce-doped YAG radiators (bottom). Electronic gain of the CCD camera was approximately three times higher in the case of Cr-oxide screen to get comparable pixel values with the Ce:YAG.

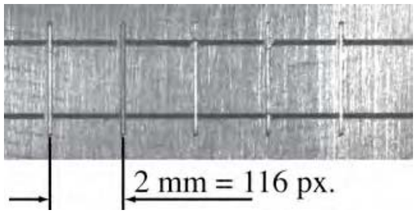

Figure 4. On-line measurement of resolution of the optical system ca be done using the calibration marks on the screen holder.

In SPARC the digital cameras of the e-meter will be part of a larger system including those needed for other optical diagnostic stations.

It will be based on the solutions developed for the TTF VUV-FEL large camera system [3].

Motors and Actuators

Motors and actuators are other important components of the SPARC e-meter. Linear actuators with stepper motors are used to control the insertion of screens and slits mask into the beamline. A differential encoder and a reference end switch guarantee reproducibility and accuracy of the movement, the latter being better than 2μm. This value is compatible with resolution needed for multi-shot measurement using a single slit.

More powerful brushless motors are used to move longitudinally the complete measurement system located between the two long bellows and to change the distance between the two crosses housing the slits mask and the screen.

Absolute position of linear movements can be obtained by, or checked with, the value given by position transducer potentiometers.

The cross housing the two slits mask can be tilted around both x and y-axes to adjust the alignment of the slits with respect to the beam direction. A stepper motor having 200 steps per turn moves each stage. μ-step movement is also possible (256 μ-steps per step).

Resolutions and accuracy of these movements have been tested and results obtained ($\Delta\theta < 2.5$ μrad) are compatible with the needed resolution of the rotational movement. Improvements are also possible by fine-tuning the assembly of mechanical components.

OPERATIONS AT PITZ

The original design of the SPARC emittance meter has been partially modified during the construction to permit its installation in the Photo Injector Test Facility PITZ at DESY Zeuthen. Mainly the table, being the support for the beamline, was modified by shortening its legs to allow installation on top of the PITZ girder. Legs extenders have been prepared and they will be used to adjust the height of the “modified” e-meter to that needed for SPARC. Furthermore we ensured mechanical compatibility between SPARC e-meter and PITZ vacuum beamline.

Figure 5. SPARC e-meter during installation at the Photo Injector Test Facility PITZ.

Alignment tools and procedures have been jointly defined.

The SPARC e-meter has been installed in the last section of the upgraded PITZ beamline [4], in the space located after the booster, before the electron beam spectrometer (Fig. 5).

The SPARC e-meter has its own control and acquisition system. Two PCs have been installed in the PITZ control room to run control panels and measurements programs. Motors are controlled via CAN bus or RS232 serial interfaces. PCs running control panels communicate with motor controllers via network using a network serial-port server. To connect a PC in the control room with digital cameras in the accelerator tunnel, because of limitation of the maximum cable length (4.5 meters), we used a fiber-optic firewire extender.

Magnetic steerers are installed at the beginning of the system, clamped around the upstream flange. They can be used to adjust the direction of the electron beam in the x and y plane.

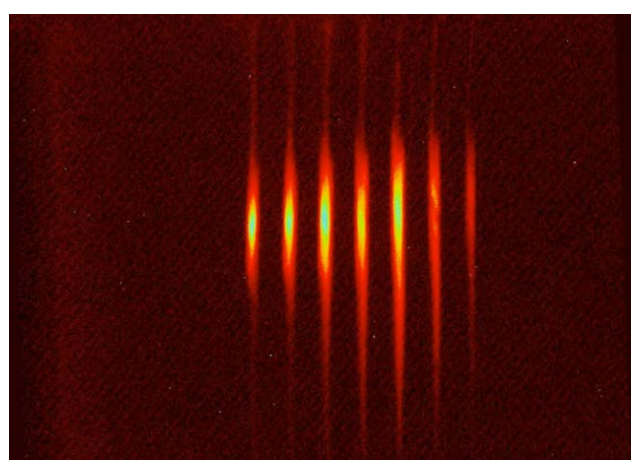

Figure 6: Picture of the beam at the YAG screen downstream the multi-slit mask.

Installation of the SPARC e-meter was completed in the beginning of July 2005 and commissioning started. Two rounds of commissioning and measurements shifts have been scheduled for the SPARC e-meter in the PITZ shift plan for July and August 2005.

The first days of operations have been dedicated to the optimization of components and to fix minor problems.

In the last part of that two-weeks shift characterization of the e-meter with low-energy beam started. We verified the reproducibility of measurements under different beam conditions and studied the strategies for the optimization of the measurements, e.g. adjusting the distance between the slits mask and the screen (Fig.6).

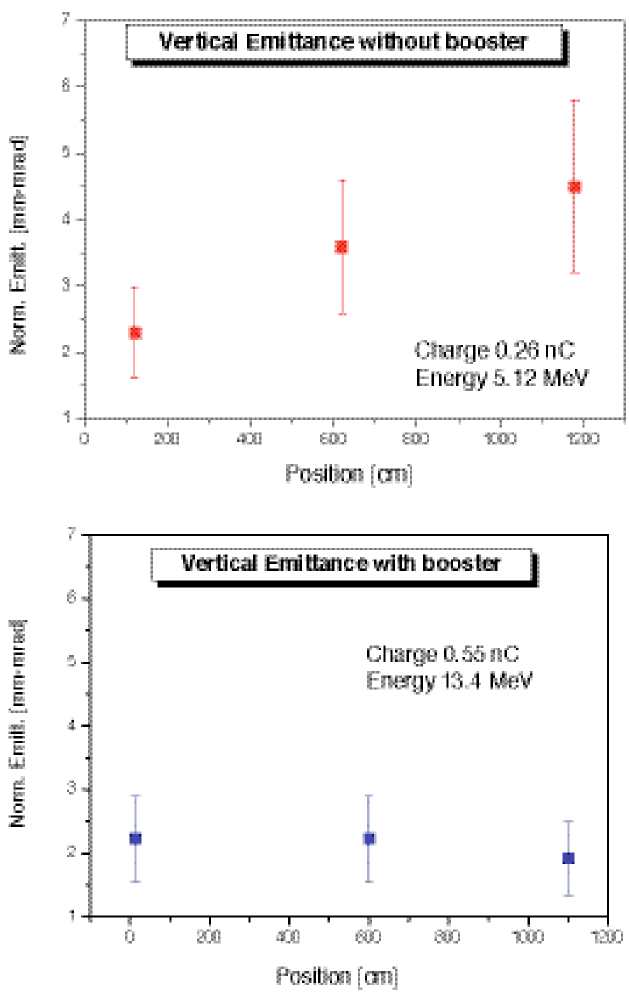

Figure 7: Preliminary result of vertical emittance measurements at PITZ with the SPARC e-meter under different conditions (booster off/on). Note that the three z-positions are not coincident in the two cases; also the beam charge is not identical.

Although the injector parameters and the transport of the beam are not yet optimized since commissioning of the upgraded PITZ facility is still in progress, preliminary measurements confirm the value of transverse emittance, as expected for the current injector settings, and its variation along the beamline. As an example we report the measurements of the vertical emittance at three different positions along the e-meter (Fig.7). The measurements show a constant increase of the vertical emittance as function of longitudinal position in the case with booster off while for the higher energy beam accelerated by the booster the value stays almost constant (within the measurement errors). These results are in good agreement with simulations for the current injector settings [5].

CONCLUSION

Construction of the SPARC Emittance-meter has been completed and it has been successfully commissioned at Photo Injector Test Facility PITZ in July 2005. Laboratory tests carried out at INFN-LNF before its shipment to DESY Zeuthen confirmed that design performances have been achieved.

Although the commissioning of the upgraded PITZ facility is still ongoing, preliminary emittance measurements have been obtained and show a good agreement with simulations for the current injector settings.

Operations with SPARC e-meter at PITZ are in progress and they will continue until the device will be shipped back to Frascati, in early Fall 2005, to be used for the measurements at the SPARC photo injector.

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