RECENT RESULTS AND FUTURE PERSPECTIVES OF THE SPARC PROJECT

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Abstract

The SPARC project foresees the realization of a high brightness photo-injector to produce a 150-200 MeV electron beam to drive 500 nm FEL experiments in various configurations, a Thomson backscattering source and a plasma accelerator experiment (these last two ones jointly with the project PLASMONX). The SPARC photoinjector is also the test facility for the recently approved VUV FEL project named SPARX. As a first stage of the commissioning, a complete characterization of the photoinjector has been accomplished with a detailed study of the emittance compensation process downstream the gun-solenoid system: this lead to the first direct experimental demonstration of emittance oscillations in a drift. The second stage of the commissioning, that is currently underway, foresees a detailed analysis of the beam matching with the linac in order to confirm the theoretically prediction of emittance compensation based on the “invariant envelope” matching and the demonstration of the “velocity bunching” technique in the linac. SASE and SEEDING experiments are foreseen by the end of the current year. In this paper we report the experimental results obtained so far and the scientific program for the near future.

INTRODUCTION

The SPARC project comprises an R&D photo-injector facility devoted to the production of high brightness electron beams to drive a SASE and SEEDED FEL experiments in the visible and UV light. The high beam quality produced by SPARC will also allow investigations into the physics of ultra-short beams, plasma wave-based acceleration, and production of advanced X-ray beams via Compton back-scattering. Moreover SPARC is the injector prototype of the recently approved SPARX project [1], that foresees the construction in the Frascati area of a new high brightness electron linac for producing SASE-FEL radiation in the 10-1 nm wavelength range. The first phase of the SPARC project, that is now concluded, consisted in characterizing the electron beam out of the photoinjector, a 1.6 cell S-band RF gun, at low energy (5.6 MeV with 120 MV/m peak field on the cathode), before the installation of the 3 S-band accelerating sections, which boost the beam energy up to 150-200 MeV. The results obtained during the first commissioning phase are reported in [2,3,4].

The second stage of the beam commissioning, that is currently underway, foresees a detailed analysis of the beam matching with the linac in order to confirm the theoretically prediction of emittance compensation based on the “invariant envelope” matching [5,6,7] and the demonstration of the emittance compensation during the “velocity bunching” experiment [8]. SASE and SEEDING experiments are foreseen by the end of the current year.

SPARC COMMISSIONING

Soon after disassembling the emittance-meter in January 2007, the installation of the whole machine took place, starting from the accelerating sections. Then the transport line to the undulators was completed, and the undulators themselves aligned on the reference beam line. The bypass and diagnostics channel was installed as last element. The present layout of the machine is shown in Fig 1. The 3 travelling wave accelerating structures have been conditioned and are now operating at a maximum gradient of 20-20-10 MV/m respectively, providing a final beam energy of 150 MeV. The low level RF control electronics to monitor and synchronize the RF phase of the accelerating structures along the linac and the laser shot on the photocathode has been also commissioned and it is now fully operative resulting in an energy stability less than 0.1 % [9]. Around the first and the second accelerating structure two long solenoids are placed to provide additional focusing (with a maximum field of 0.18 T) for matching the beam envelope with the linac, according to the invariant envelope conditions [5,6].

Figure 1: Picture of the SPARC photoinjector showing t3 accelerating structures with 2 long solenoids.

The undulator, realized by *ACCEL Gmbh* [10], is made by 6 permanent magnet sections with 2.8 cm period, 25 to 6 mm variable gap and undulator parameter k = 1.4, see Fig. 2. In between each module a 0.36 m long gap hosts quadrupoles for horizontal focusing and radiation diagnostic boxes.

Figure 2: Picture of the SPARC undulator chain during installation.

FIRST BEAM MEASUREMETS

The first beam measurement, concerning the beam characterization at full energy, started on May 2008. Unfortunately the cathode was performing at quite lower level of quantum efficiency, emission uniformity and stability with respect to the first phase: this prevented us to work at the maximum charge of 1 nC and to perform systematic studies of beam optimization in the laminar space charge dominated regime. Nevertheless, some preliminary tests of beam transport up to the exit of the third accelerating structure, checking the diagnostic systems and doing the first comparison with simulations [11], were performed. In this stage of commissioning we have been operating with a laser pulse with gaussian longitudinal profile 6-8 ps FWHM long. The bunch charge was in the range of 200 pC - 700 pC (quantum efficency in the lower order of 10^{-5}). The beam has been accelerated up to 150 MeV with an energy spread of 0.1%. During the beam transport tests the rms spot size has been measured on four YAG screens: three screens are located at the entrance of each RF structure while the fourth one is located at the exit of the linac, where the rms emittance is measured by a quadrupole scan [12] and the bunch length and slice emittance are measured with a high resolution RF deflector [13].

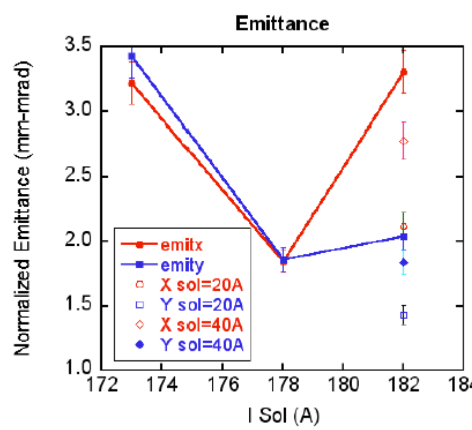

Figure 3: Emittance measurement for different configuration of the gun solenoid and the coils around the accelerating structures.

The measurements shown in Fig. 3 have been done at 500 pC and a Gaussian pulse of 8.5 ps FWHM. The best projected emittance obtained so far is slightly below 2 mm-mrad in both planes, in good agreement with PARMELA simulations (see Fig. 4). Optimal envelope matching conditions have not yet been achieved, but additional improvements in beam quality are expected [11].

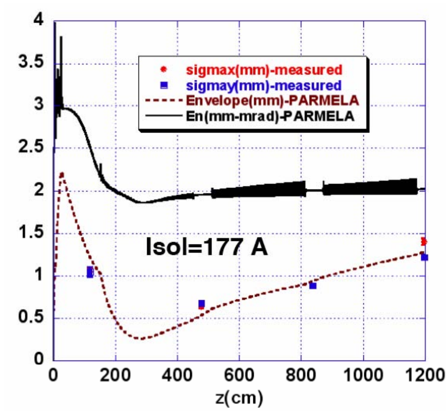

Figure 4: PARMELA simulation of the envelope and emittance corresponding to the best measurement shown in Fig. 3. The measured enevelopes (blue rectangle) are also shown.

FUTURE FEL EXPERIMENTS

One of the future experiments at SPARC, is to study and test the amplification and the FEL harmonic generation process of an input seed signal obtained as higher order harmonics generated in gases [14] and compare it with the single spike operation described in [15]. The main components of the seed source consist in the implementation of a second laser amplification chain operating in parallel to the photo-injector laser system, in the installation of a chamber devoted to the generation of high harmonics in gas, which has been realized at CEA [16], and finally in the implementation of the hardware required for injecting, in the electron transfer line connecting the SPARC linac with the SPARC undulator, the radiation generated in the chamber. A chicane deflecting the e-beam from the linac axis and a periscope allowing the injection of the harmonic beam have been realized for this purpose.

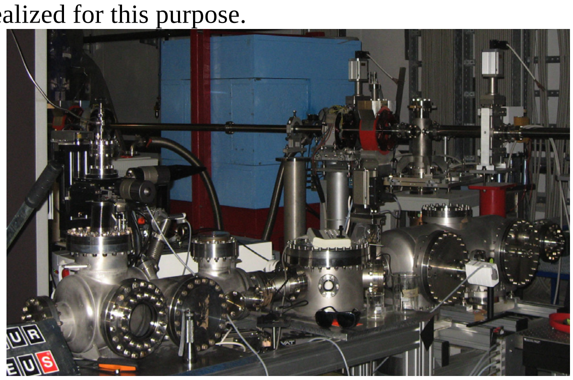

Figure 5: Harmonic generation chamber in the SPARC Hall.

The chamber was delivered to LNF in the beginning of 2007, see Fig. 5, and the laser system for the seeding experiment has been completed in November of the same year. In December the chambers have been aligned with the laser and the injection periscope, and have been commissioned. A preliminary test was concluded with the observation of the third harmonic of the Ti:Sa beam, see Fig. 6. The spatial profile of the radiation has been collected by projecting the beam on a reflecting screen. The image has been detected with an high sensitivity CCD camera (Canon IXUS 800 IS). The setup for the production of the harmonics in gas is composed by three chambers. The laser is focussed in the first chamber where harmonic generation occurs. In this chamber a cell is filled by Argon gas and is illuminated by the laser source. A second chamber is used to increase the vacuum gradient between the first chamber and the SPARC transfer line. Then the third chamber, 1.5 meters downwards, is used to match the harmonic beam with a waist located in the middle of the first undulator for a correct overlap with the e-beam. The optical mode shaping is performed using two spherical mirrors reflecting nearly at normal incidence, both equipped with motorized mounts, and an additional translation stage under the second mirror, for the adaptation of the focusing point in the undulator. The distance between the gas jet and the middle of the first undulator is about 8 m.

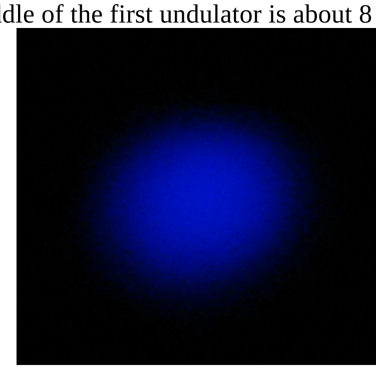

Figure 6: Spot of the UV radiation at the detection screen

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