

AN R&D PROGRAM FOR A HIGH BRIGHTNESS ELECTRON BEAM SOURCE AT LNF

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Abstract

The design of a high gradient S-band Photo-Injector system for the production and study of high brightness electron beams is in progress at the Frascati Laboratory, in the frame of a collaboration among INFN, ENEA, CNR, Univ. Roma TV, INFN and ST. This collaboration submitted last year a proposal to a dedicated call for proposals launched by our government, meant to be the first step of a R&D program strategically oriented to a large X-ray FEL initiative. This proposal was approved (December 2001), among others, for a total allocated budget of 9.5 M€ .The construction of the system is expected to start soon: it is comprised of a RF gun driven by a Ti:Sa laser to produce 10 ps flat-top pulses on the photocathode (up to a few nC bunch charge), injecting into two SLAC structures which boost the beam up to 150 MeV. We foresee to conduct investigations on the emittance correction technique and on the RF compression (velocity bunching) scheme, which is expected to increase the natural peak current (100 A) achievable at the gun exit up to a few kA level, with proper preservation of the transverse emittance. Although the system is expected to drive a FEL experiment in the UV region, it will be used also to investigate beam physics issues like surface roughness induced wake-fields, bunch length measurements in the sub-ps range, emittance degradation in magnetic compressors due to CSR and an eventual experiment of Compton backscattering to produce sub-ps X-ray pulses.

1 ORIGIN OF THE PROPOSAL

Driven by the large interest that 4th generation light sources, i.e. X-ray SASE FEL's, have raised world-wide in the synchrotron light scientific community, as well as in the particle accelerator community, and following solicitations arising from several Italian national research institutions, the Italian Government launched in 2001 a long-term initiative devoted to the realisation in Italy of a large scale ultra-brilliant and coherent X-ray source. The initiative was modulated into two phases, with anticipated budgets of 11 M€ and 96 M€ respectively: the first phase is meant to be a 3 year R&D program strategically oriented to explore the feasibility and the most crucial issues of the system which is expected to be designed and built in the second phase, aimed at the construction of the source in a 5-6 year time scale. To pursue this program, the Italian Government published two calls for proposals, in March 2001 and in December 2001 for the two phases respectively. In March 2002 the proposal SPARC, here described, was approved, among others, to be funded with 9.5 M€ over the available total budget of the first phase (11 M€): funding should be delivered soon, allowing a prompt start-up of the project. In the meanwhile, two proposals, submitted in February 2002 at the second phase of the call for proposals, are waiting a final decision of approval: one of these, SPARX, is tightly correlated to the approved project SPARC and is presented somewhere else at this conference[1].

SPARX has been submitted by a collaboration CNR-ENEA-INFN-Univ. Roma TV.

2 THE SPARC PROJECT

The overall SPARC project consists of 4 main lines of activity aiming at several goals: their common denominator is to explore the scientific and technological issues that set up the most crucial challenges on the way to the realisation of a SASE-FEL based X-ray source. These are:

1) Advanced Photo-Injector at 150 MeV

Since the performances of X-ray SASE-FEL's are critically dependent on the peak brightness of the electron beam delivered at the undulator entrance, we want to investigate two main issues - generation of the electron beam and bunch compression via magnetic and/or RF velocity bunching - by means of an advanced system delivering 150 MeV electrons, the minimum energy to avoid further emittance dilutions due to time-dependent space charge effects [2].

2) SASE-FEL Visible-VUV Experiment

In order to investigate the problems related to matching the beam into an undulator and keeping it well aligned to the radiation beam, as well as the generation of non-linear coherent higher harmonics, we want to perform a SASE FEL experiment with the 150 MeV beam, using a segmented undulator with additional strong focusing, to observe FEL radiation at 500 nm and below.

3) X-ray Optics/Monochromators

The X-ray FEL radiation will provide unique radiation beams to users in terms of peak brightness and pulse time duration (100 fs), posing at the same time severe challenges to the optics necessary to guide and handle such radiation. This project will pursue also a vigorous R&D activity on the analysis of radiation-matter interactions in the spectral range typical of SASE X-ray FEL's (from 0.1 to 10 nm), as well as the design of new optics and monochromators compatible with these beams.

4) Soft X-ray table-top Source

In order to test these optics and to start the R&D on applications, the project will undertake an upgrade of the

presently operated table-top source of X-rays at INFN-Politecnico Milano, delivering 10^7 soft X-ray photons in 10-20 fs pulses by means of high harmonic generation in a gas. This will be a very useful bench-test for the activities performed in item 3 above.

In the following, the lay-out and planned activities for items 1 and 2 will be presented in more details, being these more related to the particle accelerator field.

3 ADVANCED PHOTO-INJECTOR

Two are the main goals of this activity in the context of the SPARC project: acquiring an expertise in the construction, commissioning and characterisation of an advanced photo-injector system (which is today missing in the Italian particle accelerator community) and performing an experimental investigation of two theoretical predictions that have been recently conceived and presented by members of this study group. These are: the so-called Ferrario's working point[2] for high brightness RF photo-injectors and the velocity bunching technique to apply RF bunch compression[3] through the photo-injector, with emittance preservation.

The 150 MeV injector will be built inside an available bunker of the Frascati INFN National Laboratories: the general lay-out of the system is shown in Figure 1.

The proposed system to be built consists of: a 1.6 cell RF gun operated at S-band (2.856 GHz, of the BNL/UCLA/SLAC type [4]) and high peak field on the cathode (120-140 MeV/m) with incorporated metallic photo-cathode (Copper or Mg), generating a 6 MeV beam which is properly focused and matched into 2 accelerating sections of the SLAC type (S-band, travelling wave).

Our simulations using PARMELA indicate that we can generate with this system a beam like that needed by the FEL experiment at 150 MeV: in Figure 2 we report the longitudinal phase space distribution at the Linac exit. The rms correlated energy spread over the bunch is 0.14% with a rms normalized emittance of 1.2 mm²rad (at 1.6 nC bunch charge, 150 peak current), but the slice energy spread, calculated over a 300 μ m slice length (comparable to the anticipated slippage length), is well below 0.05 % all over the bunch.

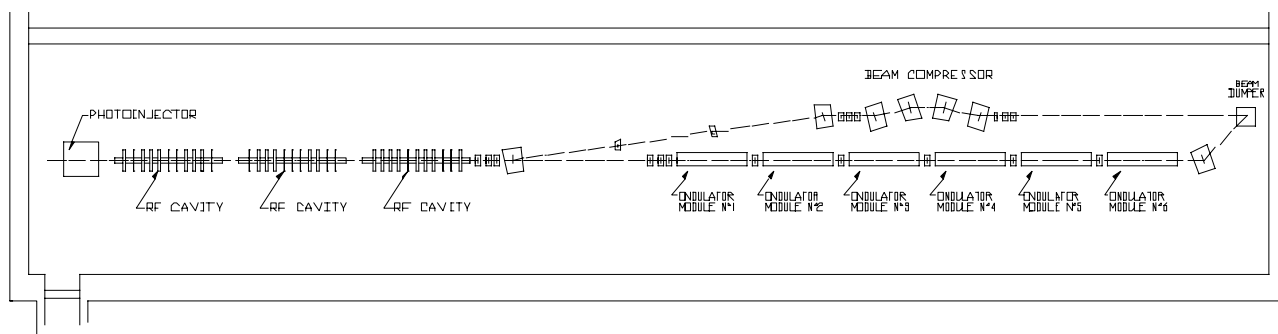


Figure 1 : Lay-out of the SPARC system.

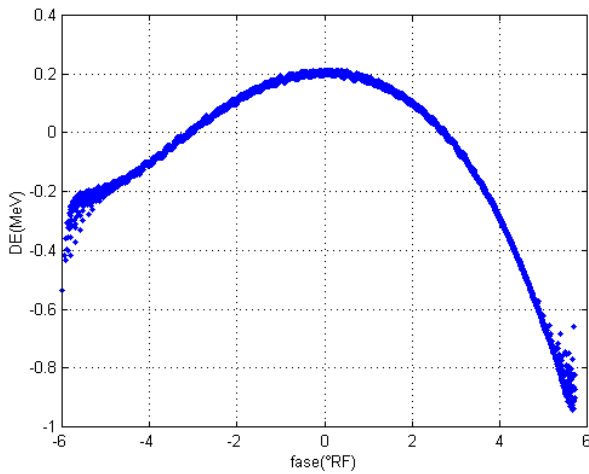


Figure 2: Longitudinal phase space distribution at Linac exit.

4 SASE-FEL EXPERIMENT

This will be conducted using a permanent magnet undulator made of 6 sections, each 2.5 m long, separated by 0.3 m gaps hosting single quadrupoles which focus in the horizontal plane. The undulator period is set at 3.3 cm, with an undulator parameter $k_w = 1.88$.

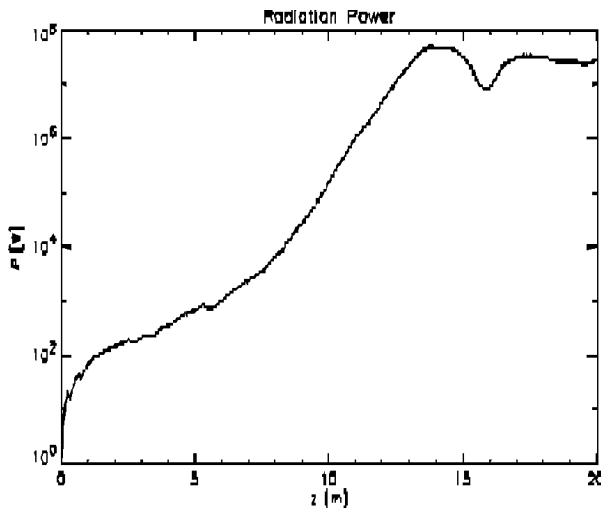


Figure 3 : Radiation Power growth along the undulator.

A simulation performed with GENESIS is reported in Figure 3, showing the exponential growth of the radiation power along the undulator: almost 10^8 Watts can be

reached after 14 m of total undulator length, on the fundamental harmonic at 530 nm. Preliminary evaluations of the radiation power generated into the non-linear coherent odd higher harmonics show that 10^7 and 7×10^5 W can be reached on the third and fifth harmonics, respectively.

5 FURTHER EXPERIMENTS

As shown in Figure 1, the SPARC lay-out anticipates two main upgrades that will be implemented in a second phase of the project: a third accelerating section which will be actually inserted between the RF gun and the 2 previous sections, and a parallel beam line containing a magnetic compressor.

The new section will be designed to study RF compression: it will support travelling waves at an adjustable phase velocity (from $v=c$ down to $v=0.999c$) in order to exploit the full potentialities of the velocity bunching technique [3]. Its design and construction will proceed in parallel to the commissioning of the SPARC injector system (RF gun + 2 standard SLAC-type 3 m sections). These tests of RF compression assume great relevance in our R&D program[5] since the general lay-out for SPARX foresees the use of a mixed compression scheme, RF compression in the photoinjector up to 700 A and one single stage of magnetic compression at 1 GeV up to the final peak current of 2.5 kA.

The second beam line will allow to conduct experiments on magnetic compression: we want to experimentally investigate CSR induced effects on emittance degradation and surface roughness wake-field effects, without interfering with the ongoing FEL experiment.

6 REFERENCES

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