STATUS OF THE SPARX FEL PROJECT*

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Abstract

The SPARX project consists in an X-ray-FEL facility jointly supported by MIUR (Research Department of Italian Government), Regione Lazio, CNR, ENEA, INFN and Rome University Tor Vergata. It is the natural extension of the ongoing activities of the SPARC collaboration. The aim is the generation of electron beams characterized by ultra-high peak brightness at the energy of 1 and 2 GeV, for the first and the second phase respectively. The beam is expected to drive a single pass FEL experiment in the range of 13.5-6 nm and 6-1.5 nm, at 1 GeV and 2 GeV respectively, both in SASE and SEEDED FEL configurations. A hybrid scheme of RF and magnetic compression will be adopted, based on the expertise achieved at the SPARC high brightness photoinjector presently under commissioning at Frascati INFN-LNF Laboratories [1,2]. The use of superconducting and exotic undulator sections will be also exploited. In this paper we report the progress of the collaboration together with start to end simulation results based on a combined scheme of RF compression techniques.

THE SPARX LAYOUT

A spectral range from 13 nm to 1 nm has been considered for the radiation. SASE-FEL's in this wavelength range require high brightness beam at the undulator entrance. In Table 1 the electron beam parameter list is reported for such a source, while in Fig. 1 the schematic layout of the accelerator is shown. A 150 MeV SPARC-like photoinjector [1] is meant to provide a 300-500 A beam, adopting the velocity bunching compression scheme. A first linac section L1 rises the beam energy up to 300 MeV, where a first magnetic chicane is foreseen mainly for comparing the overall efficiency between the two compression methods at low energy. After a second linac section L2, i.e. at the energy around 0.6 GeV, the main magnetic compressor BC2 is located rising the beam peak current up to $I_{pk}≈1$ kA, according to a 'hybrid' compression scheme consisting in one RF compression stage at low energy, plus one magnetic chicane at 0.6 GeV. A third accelerating section L3 brings the beam energy up to E≈1GeV and a first extraction dogleg DL1 drives the beam through a diagnostic section and to the first undulator where both SASE and seeding experiments in the radiation wavelength range of $\lambda_r≈$ 13 ÷5 nm are foreseen. This is what is meant for the first phase of the SPARX project. For the Phase II another linac section will bring the beam energy up to 1.5 GeV where a third magnetic chicane BC3 is foreseen to compress the beam and reach peak currents of the order of $I_{pk}≈2÷2.5$ kA. The last linac L4 brings the final energy up to E=2GeV. A second extraction dogleg DL2 provides the beam diagnostics and delivery to the second undulator for the wavelength range $\lambda_r≈$ 5÷1.5 nm

Table 1: Electron beam parameters

Beam Energy	1÷2	GeV
Peak current	1-2.5	kA
Emittance (average)	2	mm-mrad
Emittance (slice)	1	mm-mrad
Energy spread (correlated)	0.1	%
Repetition Rate	50	Hz

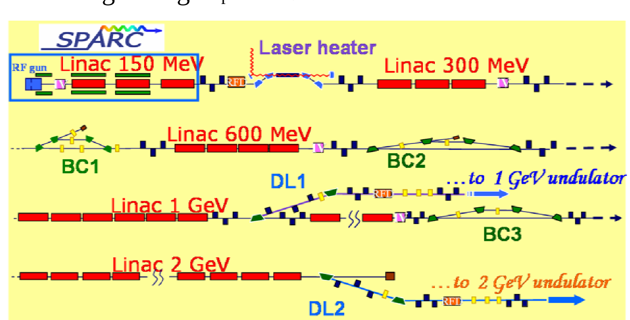

Fig. 1: SPARX Linac schematic layout

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The RF Photoinjector

The injector design is based on the SPARC high brightness photoinjector presently under commissioning at Frascati Laboratories [1,2]. It considers a 1.1 nC bunch 10 ps long (flat top) with 1.1 mm radius, generated inside a 1.6-cell S-band RF gun of the same type of the BNL-SLAC-UCLA one [3] operating at 120 MV/m peak field equipped with an emittance compensating solenoid. Three standard SLAC type 3-m TW structures each one embedded in a solenoid boost the beam up to 150 MeV. According to the simulation results the beam compression at low energy (<150 MeV), still in the space charge dominated regime, turns out to be feasible provided that a proper emittance compensation technique is adopted [4], Moreover the propagation of a short bunch in the following accelerating sections reduces the potential emittance degradation caused by transverse wake fields, while a proper phasing of the linac can control the longitudinal wake fields. A systematic study based on PARMELA code simulations has been done in order to optimize the parameters that influence the compression [5], the results of computations show that peak currents up to kA level are achievable at the injector exit with a good control of the transverse and longitudinal emittance by means of a short SW section operating at 11424 MHz [6] placed before the first accelerating section. On the other side the results obtained without the IV harmonic correction prior the RF compressor, show that is anyway possible to reach good compression factors but paying for a heavy deformation of the longitudinal bunch distribution, a strong sensitivity to RF compressor phase, and a highly non linear longitudinal phase space. In Table 2 a summary is reported of the RF compression studies results. A medium RF compression factor has been chosen and presented here as the first referring case for the SPARX beam dynamics studies, it gives an average peak current $I_{pk}\approx 400$ A at the exit of the photoinjector, as highlighted in Table 2 and shown in Fig. 2.

The Linac

In the present configuration the SPARX accelerator (PHASE I and II) is composed of four separate S-band linac sections L1, L2, L3, L4, with E= 25 MV/m accelerating field, located downstream a SPARC-like photoinjector (see Fig. 1). At the entrance of each of the three magnetic chicanes an X-band section is provided to linearize the beam longitudinal phase space prior the magnetic compression. For the 1 GeV channel of Phase I, both L1 and L2 sections are meant to work off crest, to provide the required energy chirp to compress the beam in BC2, while the on crest L3 section rises the beam energy up to E=1 GeV and contributes to the energy spread reduction. For the magnetic compression in BC3, the proper off-crest acceleration is applied also to the L3 section, while L4 contributes to the energy spread cancellation and brings the beam energy up to E=2GeV.

Table 2: RF compressor parameter

RF phase range	B1,B2,B3 (gauss)	Current (A)	Emittance (µm)
-60°/-75°	1200,0,0	117-151	0.7
-75°/-83°	1200,1400,0	151-249	0.8
-83°/-87°	1200,1400,0	249-458	1.3
-87°/-91°	1200÷1800	458-1180	2.8

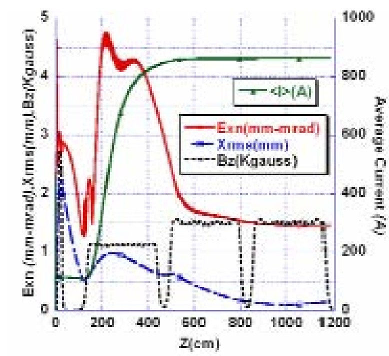

Fig. 2: Average current, transverse emittance and envelope, axial magnetic field vs. z for a final 450 A electron beam., tracked with PARMELA [7].

The invariant envelope matching condition will be applied to the lattice as proposed by Ferrario *et al* [8].

The Bunch Compression

To increase the beam current up to the kA order magnitude a magnetic compression stage is foreseen in the BC2 chicane for the beam with final energy E=1GeV, $I_{pk}\approx 1$ kA (Phase I), and in the BC3 chicane for the beam with final energy E=2 GeV, $I_{pk}\approx 2.5$ kA (Phase II). With the previously described setting for the RF photoinjector, a further compression factor of 2 in the BC2 chicane produces an average peak current $I_{pk}\approx 1$ kA, able to reach SASE saturation in the wavelength range of $\lambda_r\approx 10\div 6$ nm at the energy of 1GeV. The parameters of the BC2 compressor for this case are shortly listed in Table 3. The photoinjector incoming beam has been generated with PARMELA, considering a thermal emittance value of $\varepsilon_x\approx 0.6$ µm, the downstream tracking in the chicane has been performed with ELEGANT [9]. The tracking in the BC2 chicane has also been checked with PARMELA and CSRtrack [10] codes in order to clarify the role played by the space charge effect in the transverse emittance dilution [11]. The three codes outputs show substantially that for a peak current around $I_{pk}\approx 1$ kA the space charge effect doesn't heavily contribute to dilution of the transverse emittance.

Table 3: BC2 compressor parameters .

Beam Energy	E	GeV	0.5
Initial rms bunch length	σ_{zi}	mm	210
Final rms bunch length	σ_{zf}	mm	90
Incoming energy spread	$\sigma_{\delta i}$	%	.45
Momentum compaction	R_{56}	mm	-27
2^{nd} order mom. compaction	T_{566}	mm	+42

A hybrid compression scheme with velocity bunching and BC2 only is nevertheless foreseen and RF compression tests will be performed at the SPARC facility in the second half of 2007. After the BC2 compressor the energy of the beam is raised up to 1 GeV and the first dogleg DL1 delivers the beam to the 1 GeV undulator system, where both SASE and seeded radiation schemes are foreseen for a radiation length in the range of $\lambda_r \approx 13 \div 5$ nm. After the 1 GeV DL1 dogleg insertion another linac section brings the beam energy up to 1.5

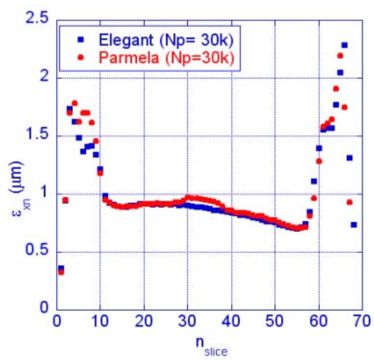

Figure 3: Slice analysis of the horizontal beam emittance after BC2 compressor as obtained with Elegant and Parmela code simulation.

GeV where the third magnetic compressor BC3 is located, in order to reach a peak current of the order of $I_{pk} \approx 2.5$ kA. After the last linac, at around 2 GeV, a second dogleg DL2 brings the beam to the second undulator system for radiation length in the range of $\lambda_r \approx 1.5 \div 5$ nm. A special attention is devoted to the space charge effect relevance in both the BC2 and BC3 compressors: in Fig. 3 the simulation results for the transverse beam emittance are reported as obtained with the Elegant and Parmela codes. A projected emittance dilution of the 30% is obtained so far; the compressor optimization is still in progress in order to further reduce the transverse dilution due to the space charge effect.

The undulator and FEL

Both SASE and seeded radiation modes are foreseen at each of the two energy steps of the SPARX channel. As an example in Table 4 the very preliminary parameter list is reported for the two undulators of a possible seeding experiment at 2.3 GeV. In Fig. 4 the radiation spectrum is shown for the fifth harmonic of the λ=13 nm seed. An intensive study is ongoing to explore the most suitable configurations according to the user community needs.

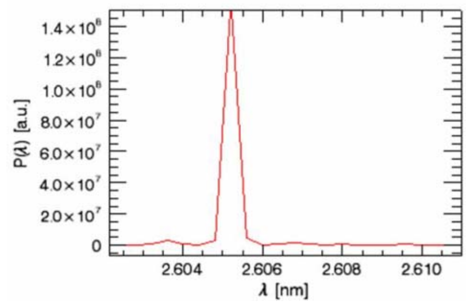

Figure 4: Radiation Spectrum of the fifth harmonic for a possible seeded scheme at 2.3 GeV.

Table 4: Preliminary Parameter list of Seeding Experiment example at 2.3 GeV. (Fig. 7)

	Undulator 1	Undulator 2
Periods	21	42
Sections	9	10
Period(cm)	5.4	2.7
K	4.299	2.51

CONCLUSIONS

The SPARX project aim is the generation of electron beams characterized by ultra-high peak brightness at the energy of 1 and 2 GeV, (Phase I and II), for SASE and SEEDED FEL experiments in the range of $\lambda_r \approx 13.5 \div 1.5$ nm. It is jointly supported by the Italian Government and Regione Lazio with a five years schedule for the first phase. The critical components such as the RF-compression scheme, magnetic chicane, etc. will be tested during the phase II of the SPARC project. A first general layout for SPARX has been proposed and first start to end simulations for the 1 GeV channel of Phase I, have been presented using a “hybrid” scheme of bunch compression with RF and magnetic compression techniques involved together.

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