STATUS OF THE SPARX FEL PROJECT

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Abstract

The first phase of the SPARX project, now funded by MIUR (Research Department of Italian Government), is an R&D activity focused on developing techniques and critical components for future X-ray FEL facilities. This project is the natural extension of the activities under development within the ongoing SPARC collaboration. The aim is the generation of electron beams characterized by an ultra-high peak brightness with a linear accelerator based on the upgrade of the existing Frascati 800 MeV LINAC and to drive a single pass FEL experiment in the range of 3-5 nm, both in SASE and SEEDED FEL configurations, exploiting the use of superconducting and exotic undulator sections. In this paper we discuss the present status of the collaboration.

INTRODUCTION

The first phase of the SPARX project is now funded by MIUR, (Research Department of Italian Government) as an R&D activity focused on developing techniques and critical components for future X-ray FEL facilities. Two basic lines manage the activity:

a) experimental tests on RF compression techniques by means of using the SPARC [1] high brightness Photoinjector presently under installation at Frascati INFN-LNF Laboratories;

b) explore the feasibility of soft and hard X-rays sources in the SASE and seeding schemes in the SPARX test facility (SPARXINO), upgrading in energy and brightness the existing Frascati 800 MeV Linac at present working as injector system for the DAΦNE Φ-factory [2]. Other on going issues are the studies of high repetition rate S-band gun, high Quantum Efficiency cathodes, high gradient X-band RF accelerating structures and harmonic generation in gas [3].

THE SPARXINO TEST FACILITY

A spectral range from 10 nm to 1 nm has been considered for the radiation. In Table 1 a preliminary parameter list is reported while in Fig. 1 the schematic layout of the SPARXINO test facility is shown. It consists of an advanced high brightness photoinjector followed by a first linac, Linac1, that drives the beam up to 500 MeV with the correlated energy spread required to compress the beam in the following magnetic chicane. The second linac, Linac2, drives the beam up to 1.2 GeV while damping the correlated energy spread taking profit of the effective contribution of the longitudinal wake fields provided by the S-band accelerating structures. Three matching sections TL1, TL2, and TL3 are provided at the entrance of the two linac and the magnetic chicane. This linac design integrates a rectilinear RF compressor in a high brightness photoinjector, as proposed in [4], thus producing a 300-500 A beam in the early stage of the acceleration. The SPARXINO linac might be the first FEL experiment operating with RF and magnetic

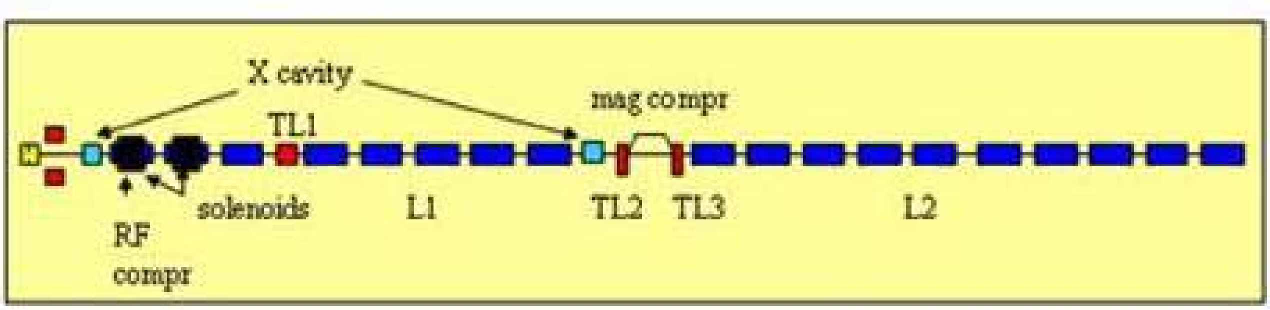

Figure 1: Schematic layout of the SPARXINO test facility.

compressor in the same linac. The choice to compress the beam at low energy (<150 MeV) when it is still in the space charge dominated regime, results not harmful from simulations provided a proper emittance compensation technique is adopted [4]. In addition the propagation of a shorter bunch in the first linac reduces the potential emittance degradation caused by transverse wake fields and longitudinal wake fields result to be under control by a proper phasing of the linac. A comparison between RF and magnetic compression technique is scheduled during the SPARC operation.

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	%

The Photoinjector

The SPARXINO photoinjector consists in a RF gun injecting into three SLAC type accelerating sections. In Fig. 2 the schematic layout is reported. The first phase of the project foresees the use of the SPARC facility [1] to test RF compression techniques to generate high brightness electron beams. The SPARC photoinjector consists of an RF gun operated at S-band, with a peak field on the cathode of 120 MV/m and an incorporate metallic photo-cathode, followed by an emittance compensating solenoid and three travelling wave SLAC type accelerating structures (TW). To operate in the RF compression scheme solenoids are placed around the first two sections for the emittance compensation and an X-band cavity is placed after the gun exit to compensate the non-linear contribution to the longitudinal phase space beam distribution. A systematic study [5] has been carried on with the PARMELA code [6] to explore the possible configurations and to study the stability of the system. The results are reported in Table 2 together with RF-compressor set-up parameters. In view of the system application as injector for SPARXINO 3-5 nm FEL facility two working points have been chosen for the future detailed study: the first having a peak current I_{pk}≈400 A and projected normalized emittance $\varepsilon_n \approx 1.1\mu$m,

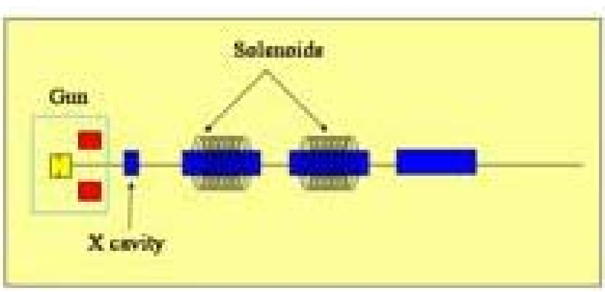

Figure 2: Schematic layout of the SPARXINO photoinjector.

Table 2: RF compressor parameters: phase tuning range for the first TW section, magnetic field on solenoids, electron beam average peak current and maximum projected normalized emittance in the range at the exit of the third TW structure.

RF compressor Phase range	B1,B2,B3 (gauss)	Current (A)	Max. 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°	Ramped from 1200 to 1800	458-1180	2.8

mostly suitable for a second compression stage through the magnetic chicane, and the second with I_{pk}≈ 800 A, ε_n≈1.5 μm, intrinsically interesting for its high slice brightness. In Fig. 3 a) and b) the peak current, normalized emittance, beam envelope and solenoid filed map are reported along the injector for the two cases.

The Linac

The SPARXINO linac is based on the upgrade of the existing DAΦNE injection facility as reported in Fig. 4.

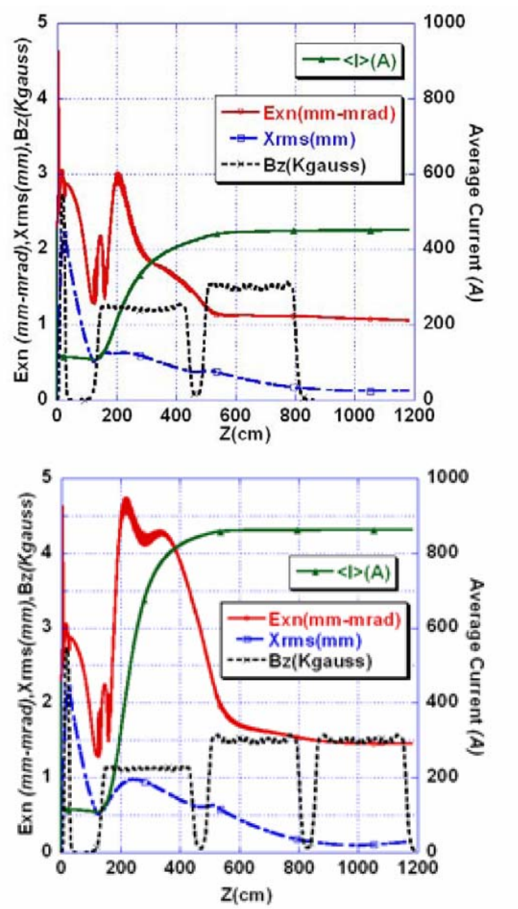

Figure 3: Peak current, normalized projected emittance, beam envelope and solenoid field map for two RF compressor working points.

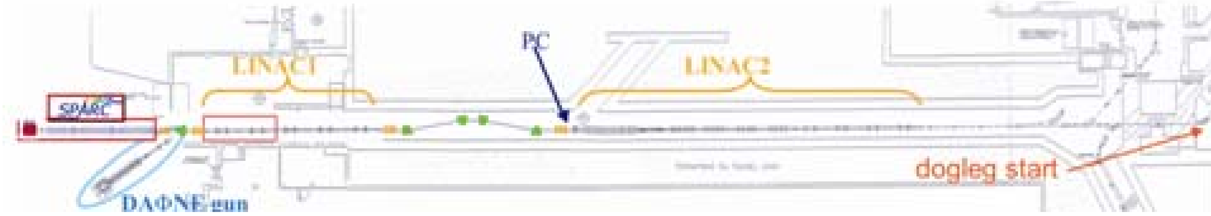

Figure 4: SPARXINO proposed layout.

The DAΦNE injection system is a 60 m long LINAC [7] equipped with 15 S-band (2.865 GHz) SLAC-type 3 m long accelerating structures driven by four 45 MW klystrons each followed by a SLED peak power doubling system. The Linac energy upgrade to 1.2 GeV can be achieved by upgrading the accelerating field of the existing units up to 25 MV/m. The Linac waveguide network must also be modified in order to supply two accelerating units per RF station. This system configuration requires four new 45 MW klystrons. More over the availability for inserting four more SLAC-type sections will provide the possibility to reach a final energy of 1.5 GeV. In order to reach the current values required for the FEL application in the 3-5 nm range a second magnetic compression stage is required after the RF compressor. A magnetic chicane is placed for this purpose after the first linac L1 set to provide the needed correlated energy spread, while the second linac L2 helps to remove it before the injection into the undulator. A schematic drawing is shown in Fig. 5. For both the two chosen working points previously described the beam

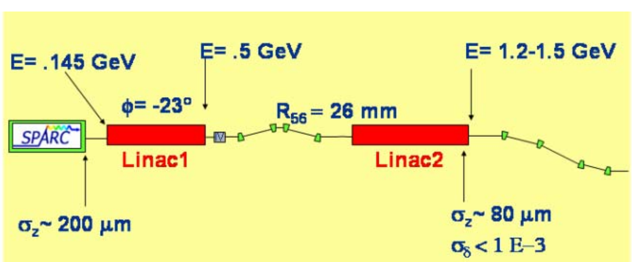

Figure 5: Schematic layout of the RF+magnetic compression scheme.

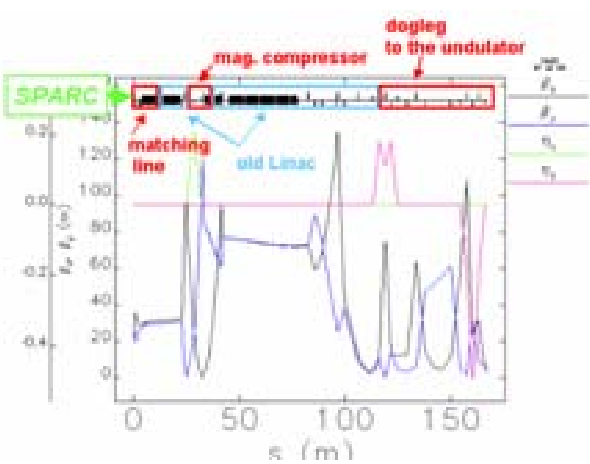

Figure 6: The SPARXINO lattice.

propagation through the SPARXINO linac mostly occurs in a space charge dominated regime, namely at the exit of the photoinjector and after the magnetic compression. A detailed study has been devoted to the SPARXINO beam dynamics as reported in [8], from this analysis it turns out that the invariant envelope condition has to be applied at the entrance of the two linac sections, L1 and L2, to control and damp the emittance oscillation. The SPARXINO lattice is embedded in the existing DAΦNE LINAC as it is shown in Fig. 6. After the linac exit a 43 m dogleg is foreseen to inject the beam into the undulator.

For the medium RF compression working point, i.e. $I_{pk}\approx 400$ A 50K particle tracking has been performed with the Elegant code [9] switching alternatively on/off the X-band RF cavity at the exit of the RF gun and at the entrance of the magnetic chicane respectively (Fig. 1).

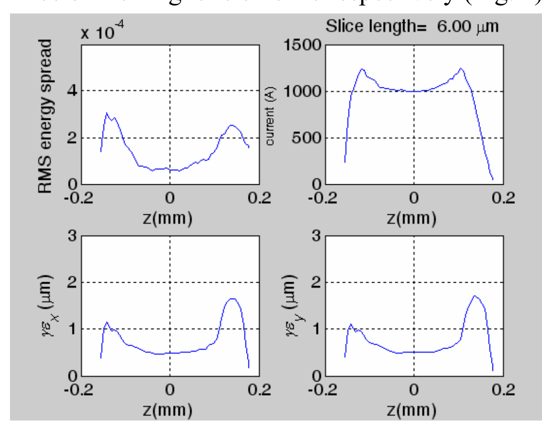

Figure 7: Energy spread, peak current and transverse emittance along the bunch, with the X-band ON at the RF gun exit.

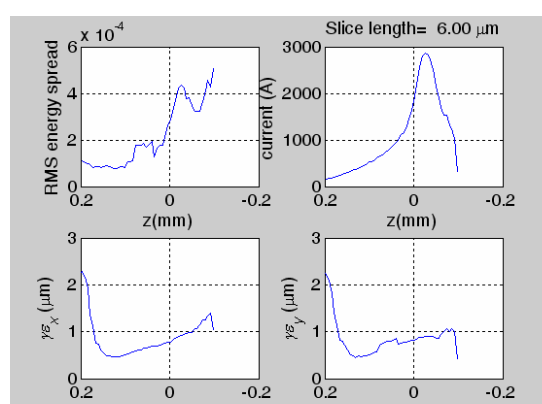

Figure 8: Energy spread, peak current and transverse emittance along the bunch, with the X-band ON at the magnetic chicane entrance.

The slice analysis and the current distribution of the beam tracked up the undulator entrance are reported in Fig. 7-8. In the first case a I_{pk}≈1200 A is obtained with a lasing efficiency of 80% calculated with Ming-Xie formulas [10] applied for λ=5nm and 22 m of saturation length. In the second case we obtain I_{pk}≈2800 A and quite the 90% of the slices seem to reach the saturation.

The undulator

We report here the preliminary simulation results obtained with the PERSEO code [11] of a free electron laser operating in SASE and seeded configurations. The simulations are meant to provide a general overview of the characteristics of the radiation that may be obtained with the SPARXINO facility and a SPARC-type undulator [1]. The undulator configuration, based on non-homogeneous undulator sections with different period length, should provide high flexibility, short saturation length in the water window spectral region and suitability for a seeding configuration.

The considered electron beam parameters are those reported in Table 1, while a summary of the simulation results for the **SASE** mode are listed in Table 3. It has been assumed that the e-beam is transported along the undulator with a Twiss matching parameter β=4.5 m in all the configurations. The saturation length refers to the effective magnetic length of the undulator.

Table 3: Summary of simulation results for the **SASE** configuration

Wavelength (nm)	5	15
Beam Energy (GeV)	1.4	1.0
UM strength K	1.83	2.49
Saturation length (m)	18	13
Pulse energy (mJ)	1.9	2
Peak power (GW)	7	9
Pk. Pwr Dens. (GW/cm$^{2)}$	7 10^4	6$10^4$
Beam size at saturation (rms μm)	40	50
Bandwith (%)	0.22	0.4
1stord. coherence length (μm)	0.9	2
Pulse length (rms fs)	120	130
Flux (Phot/s/0.1%bw)	9 10^{25}	2 10^{26}
Brightness (Phot/s/0.1%bw/(μrad)^2)	8 10^{30}	1 10^{31}
Shot to Shot Power fluct. (%)	14	18

For the **seeded** mode the simulation has been repeated for the λ=15 nm case injecting a seed with Gaussian profile, rms length of 20 fs. The seed energy is 2.7 nJ, corresponding to a peak power of 50 kW. Such a source can be realized with the mechanism of the high order harmonic generation in gas jet (HHG) [12], an experimental test of this scheme is under development at SPARC [3]. In Table 4 the main characteristic of the **seeded FEL** are listed.

Table 4: Summary of simulation results for the **seeded** configuration

Wavelength (nm)	15
Beam Energy (GeV)	1.0
UM strength K	2.49
Saturation length (m)	9
Pulse energy (mJ)	0.7
Peak power (GW)	20
Pk. Pwr Dens. (GW/cm$^{2)}$	1 10^5
Beam size at saturation (rms μm)	50
Bandwith (%)	0.04
1stord. coherence length (μm)	10
Pulse length (rms fs)	30
Flux (Phot/s/0.1%bw)	4 10^{26}
Brightness (Phot/s/0.1%bw/(μrad)^2)	2 10^{31}
Shot to Shot Power fluct. (%)	-

CONCLUSIONS

The status of the SPARX project has been presented concerning the activity on the RF compression techniques and the SPARXINO test facility study and design. Two RF compressor working points have been chosen to be analyzed in detail and tested in the SPARC test facility presently under installation at Frascati. The SPARXINO test facility layout has also been presented together with an updated lattice design based on the invariant envelope condition. Preliminary simulation results for the FEL have been also reported based on SASE and seeded configurations.

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