THE SPARX-FEL PROJECT

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Abstract

The SPARX-FEL project is meant to provide ultra high peak brightness electron beams, with the energy ranging between 1.5 - 2.4 GeV, in order to generate FEL radiation in the 0.6-40 nm range. The construction will start with an upgrade of the existing SPARC [1] at 750 MeV, to reach in the near future 1.5 GeV; besides the basic S-band technology the C-band option is also presently under study. Both RF-compression and magnetic chicane techniques are foreseen to provide the suitable electron beam to each one of the three undulator systems which will generate VUV-EUV, Soft X-Rays and Hard X-rays radiation respectively. Dedicated beamlines will distribute the beam to the downstream undulators for applications in basic science and technology. In this paper we present the status of the project funded by the Italian Department of Research, MIUR, and by the local regional government, Regione Lazio, that foresees the construction of a user facility inside the Tor Vergata campus by collaboration among CNR, ENEA, INFN and the Università di Tor Vergata its.

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The SPARX (Sorgente Pulsata Autoamplificata di Radiazione X) FEL covers a radiation region complementary to those of other existing or in construction facilities, such as FLASH ($4<\lambda<40$ nm), FERMI ($10<\lambda<100$ nm), X-FEL ($0.1<\lambda<1.6$ nm), LCLS ($0.15<\lambda<1.5$ nm), and will produce, with special magnets, radiation up to the THz region. The project is planned as a research infrastructure in Tor Vergata University campus, an area about 1.5 km long, that does not limit the expansibility of the facility for future upgrades. In June 2009 the Technical Design Report and the Scientific Case have been completed [1]; they foresee an evolutionary project with additional steps based on the SPARC test facility [2]. The project will start with an energy upgrade of existing SPARC up to 750 MeV, in order to achieve in the first harmonic the VUV spectral region. Further upgrades are foreseen in order to reach the soft X-Rays spectrum, tuning the machine, from 5-6 Å to 30-40 nm. In this way the facility will easily cover in its first harmonic the water window spectral region (ranging from 2.3 to 4.4 nm).

The subnanometer FEL emission (5-6 Å) is quite suitable for molecular structure studies and it can be further extended down to 1 Å with the use of third and fifth harmonics. The complete design of the SPARX is already reported in [3] and [4]. Here we focus on the 750 MeV SPARC upgrade.

THE ACCELERATOR LAYOUT

The SPARX accelerator is made of S-band type accelerating sections at f_{rf}=2.856 GHz and Eacc= 23.5MV/m. The first part Linac-0 is composed of three 3m long accelerating sections: it consists of SPARC photoinjector already developed and in operation at LNF-INFN.

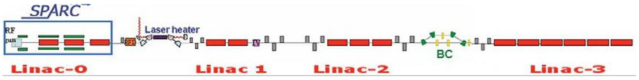

Figure 1: SPARX accelerator layout

A diagnostic section, following the transport line, provides energy and beam emittance measurements. In particular also slice parameters will be measured allowing a 6d phase space characterization of the electron beam coming from the injector.

A laser heater chicane is included in the scheme in order to raise the uncorrelated beam energy spread. The layout also includes the LINAC-1 (two accelerating sections), LINAC-2 (three accelerating sections) and LINAC-3 (six accelerating sections), a short X band sections (60 cm) and a magnetic compressor as shown in Fig. 1.

The longitudinal beam compression is realized by means of velocity bunching in the photoinjector and by magnetic chicance. The LINAC-0, or SPARC photoinjector, works with bunches of 250 pC, and using the "velocity bunching" regime, successfully tested in SPARC [5] produces a peak current of 120 A.

The Tstep code was used for the studies and the optimizations of beam dynamics in the photoinjector, using 50000 macro-particles to consider also the effect produced by the space charge. The remaining part of the accelerator was optimized with ELEGANT code, propagating up to LINAC 3 the particles coming from LINAC-0, taking into the account the longitudinal and transversal wakefield in the accelerating sections and the Coherent Synchtron Radiation (CSR) in the magnetic compressor.

The accelerating sections work at -16.5° phase, to generate the correct energy phase correlation fot the magnetic compression and incresing the beam energy up to 410 MeV. The compressor is a magnetic chicane with R_{56}=29 mm, squizing the beam down to 47 µm. Transverse emittance diluition, due to CSR, is minimized using a curvature angle below 3°.

The electron transfer line from the linac to the undulator entrance are extensivly described in the SPARX TDR [3]. In this configuration there will be a low energy line for a total length of about 40 m.

The principal beam parameters of the machine are shown in Table 1.

Table 1: Parameters list

Energy	**(GeV)**	**E**	**0.75**
Peak current	(kA)	I_{pk}	0.7
Normalized transverse emittance slice	(μm)	ε_n	0.5
Correlated energy spread	(%)	$\sigma\delta$	0.1
Photon Radiation wavelength	(nm)	λ_r	20÷30

FEL AND UNDULATOR SYSTEMS

The beam is injected thought a transfer line in the Undulators. The undulators are divided in two modulators with long period (44 mm) followed by eight section SPARC-type (period 28 mm) and one section with short period (17 mm) acting as a radiator. The Undulator is so built with eleven modules where the first two modulators can be used both to extend the length in order to obtain the saturation in SASE regime and to modulate the beam for seeding amplification. The undulators SPARC-type amplify the radiation and the last module operates as a radiator and frequency multiply. In Fig.2 is shown the layout of the undulators.

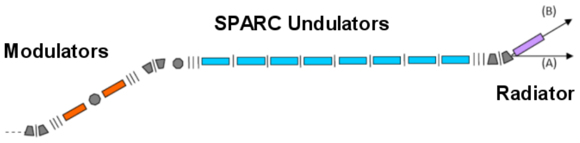

Figure 2: SPARX undulators layout. The bending angles are not in scale, being smaller than shown in the picture

The undulators parameters are shown in Table 2.

	P(mm)	Gap(mm)	Kmax	#p	L(m)
Modulator	44	9	4.643	45	2.068
SPARC	28	7.2	2.540	77	2.156
Radiator	17	6	1.140	150	2.550

Table 2. VUV undulator parameter list. P=period length; L=total length of the module, #p number of periods.

This flexible configuration allows several scenarios:

a) SASE radiation in first and higher armonics;
b) radiation with shorter wavelength in the last section of radiator with short period;
c) tunability of the radiation wavelength by changing the undulator gap;
d) seeding operation.

The parameters of the FEL radiation for the fundamental harmonic are reported in Table 3.

Table 3. Radiation parameters list

	Units	*U1*
Electron Beam energy	GeV	0.750
Wavelength	nm	27.4
Photon energy	eV	45.24
Peak power	GW	0.948
Average power	W	-
Bandwidth (FWHM)	%	0.23
Pulse duration (FWHM)	fs	89
Repetition rate	Hz	100-50
Number of photons per pulse	#	2.66×10^{13}
Peak brilliance*		6.2×10^{29}

**standard units:*

The fundamental wavelength of the radiation is 27.41 nm. The graph of the energy for pulse versus distance is shown in Fig.3. The saturation is reached inside the 15 meters of the undulators length.

Regarding the b) scenario the radiator parameters are choosen in such way that the fundamental harmonic is tuned to fifth harmonic of the SPARC undulator and so the third harmonic of the radiator corresponds to the 15th of the SPARC undulator. This solution allows to obtain coherent radiation down to 1.83 nm.

In the c) configuration it is possible to obtain different working points, from 20 nm down to 2.25 nm using different gap values and the radiator tuned to the third harmonic of the SPARC undulator.

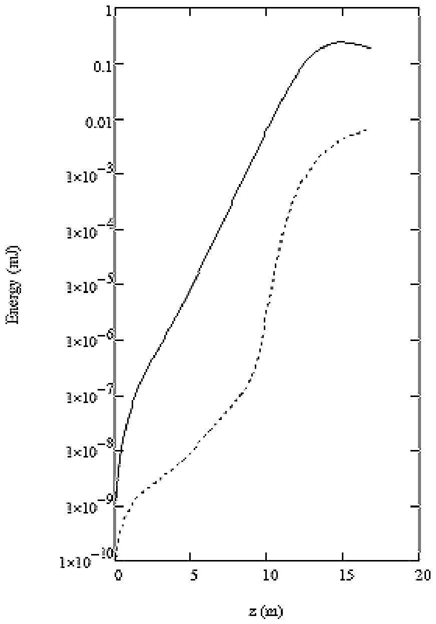

Figure 3: Energy per pulse in the fundamental harmonic. The dashed line represents the third harmonic.

The seeding operation foresee the injection of a coherent seed together with the electron. The radiation wavelength is the 27th harmonic of the Ti-Sa (29.6 nm) tuned with the fundamental frequency of the undulator acting as modulator. The modulated electron beam is then injected in the SPARC undulators tuned on the third harmonic. See Fig.4 for the configuration of the SASE and SEEDING operation

The interaction between the electron beam and the seed (50 kW, 50 fs fwhm pulse length, 2.5 nJ energy) in the modulators induces a density modulation in the beam paving the way to the coherent emission to higher wavelength in the undulator sections.

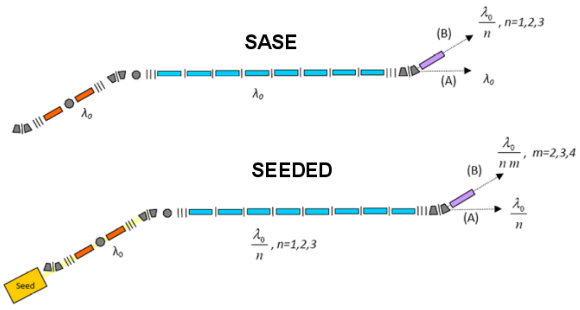

Figure 4: SASE and SEEDED configurations

The ligth transport of the radiation produced by the FEL source is designed to be used in the full spectral range starting from the fundamental harmonic down to the fifth harmonic (4 nm). The disperive optics are designed to have the minimum impact on the duration of the single FEL pulse, allowing time-resolved spectroscopy.

CONCLUSION

The first step of the SPARX project will be the energy upgrade of the existing SPARC photo-injector running at LNF up to 750 MeV. Simulations were performed in order to optimize the working point using different codes to take into the account space charge in the photo-injector and wakefield and CSR in the rest of the machine. An hybrid compression scheme, using rectilinear RF compressor in the velocity bunching regime and magnetic chicane with moderate bending allows to reach high peak current in the order of 0.7 kA, keeping emittance dilution due to CSR at moderate level.

Eleven undulators modules will be installed, with different periods and gaps. Several schemes are proposed to produce in different scenarios coherent radiation from the fundamental wavelength at 27.4 nm down to few nm.

The use of a configuration which a seeding radiation is also foresees.

REFERENCES

[1] www.sparx-fel.it.

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[5] M. Ferrario et al., "Experimental Demonstration of Emittance Compensation with Velocity Bunching", PRL 104, 054801 (2010).