Conceptual Design of a Soft X-ray SASE-FEL Source

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Abstract. FELs based on SASE are believed to be powerful tools to explore the frontiers of basic sciences, from physics to chemistry to biology. Intense R&D programs have started in the USA and Europe in order to understand the SASE physics and to prove the feasibility of theese sources. The allocation of considerable resources in the Italian National Research Plan (PNR) brought about the formation of a CNR-ENEA-INFN-University of Roma "Tor Vergata" study group. A conceptual design study has been developped and possible schemes for linac sources have been investigated, bringing to the SPARX proposal. We report in this paper the results of a preliminary start to end simulation concerning one option we are considering based on an S-band normal conducting linac with high brightness photoinjector integrated in a RF compressor.

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THE SPARX PROPOSAL

Driven by the large interest that X-ray SASE FEL's light sources 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 realization in Italy of a large scale ultra-brilliant and coherent X-ray source. The allocation of considerable resources in the Italian National Research Plan (PNR) brought about the formation of a CNR-ENEA-INFN-University of Roma "Tor Vergata" study group. A conceptual design study has been developped and possible schemes for linac sources have been investigated bringing to the SPARX proposal.

Two spectral complementary regions around 13.5 nm and 1.5 nm, are considered for the radiation source. In order to generate the SASE-FEL at these wavelengths, it is necessary to produce a high brightness beam to inject inside two long undulators. A preliminary analysis of the beam parameters required for such a source leads to values reported in Tab. 1.

TABLE 1. Electron beam parameter.

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

We report in the next sections the results of a preliminary start to end simulation concerning one option we are considering based on an S-band normal conducting linac.

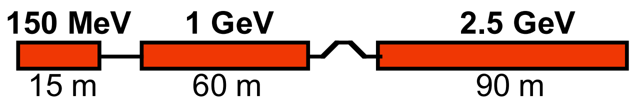

FIGURE 1. Linac scheme of SPARX project.

The basic scheme is shown in Fig. 1 and consits of an advanced high brightness photoinjector followed by a first linac that drives the beam up to 1 GeV with the correlated energy spread required to compress the beam in a subsequent magnetic chicane. The second linac drive the beam up to 2.5 GeV while damping the correlated energy spread tacking profit of the effective contribution of the longitudinal wake fields provided by the S-band accelerating structures. A peculiarity of this linac design is the choice to integrate a high brightness photoinjector in a rectilinear RF compressor, as recently proposed [1], thus producing a 300-500 A beam in the early stage of the acceleration. The potentially dangerous choice to compress the beam at low energy (<150 MeV) when it is still in the space charge dominated regime, results to be not a concern provided that a proper emittance compensation technique is adopted [2], a possibility that is not viable in a magnetic chicane. 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 results to be under control by a proper phasing of the linac.

HIGH BRIGTHNESS PHOTOINJECTOR WITH RF COMPRESSOR

The injector preliminary design considers a 1.6 nC bunch 10 ps long (flat top) with 1.2 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 140 MV/m peak field equipped with an emittance compensating solenoid. Three standard SLAC 3-m TW structures each one embedded in a solenoid boost the beam up to 150 MeV. With a proper setting of accelerating sections phase and solenoids strength it is possible, applying the compression method described in [2], to increase the peak current preserving the beam transverse emittance. In the present case we have got with PARMELA simulation a bunch average current of 440 A with a normalized rms emittance below 1 mmmrad. The low compression ratio (a factor 3) has been choosen to keep the longitudinal emittance as low as possible in order to simplify the second compression stage. We used the first two TW sections as compressor stages in order to achieve a gradual and controlled bunching, the current has to grow about at the same rate of the energy, and we increased the focusing magnetic field during the compression process. An optimised RF compressor parameters set is reported in Tab. 2.

TABLE 2. RF compressor parameters

TW Section	I	II	II
Gradient [MV/m]	15	25	25
Phase [Deg]	-88.5	-67	0 (on crest)
Solenoid field [G]	1120	1400	0

Fig. 1 (left) shows the current growth during bunch compression until 150 MeV, envelope and emittance evolution are also reported (right), showing the emittance compensation process driven by the solenoids around the accelerating section that keep the bunch envelope close to an equilibrium size during compression [2].

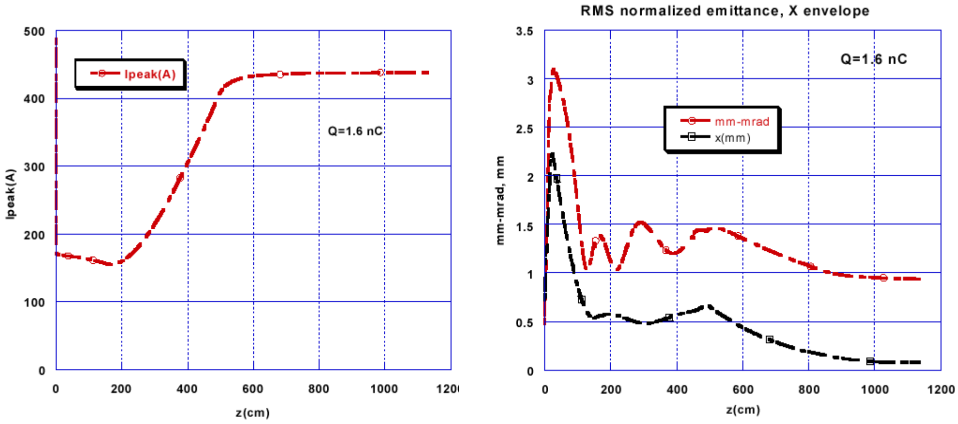

FIGURE 2. Rms current (left), rms norm. emittance and rms beam envelope (right) along the injector, up to 150 MeV.

A dedicated R&D program (SPARC project [5]) is envisaged at LNF-INFN in collaboration with CNR-ENEA-INFM-ST-Tor Vergata University. Its aim is the generation of electron beams with ultra-high peak brightness to drive a SASE-FEL experiment at 520 nm, performed with a 12m undulator following the linac.

THE LINAC

The accelerator dedicated to the FEL-SASE source has the task of accelerating high brightness electron bunches up to the energy of 2.5 GeV including a second compression stage. Linac1 consists of 15 S-band TW structures, operating at 20 MV/m and the beam is propagated 20 degrees off crest. In the Linac2 additional 24 accelerating structures are foreseen with the same gradient and the beem is propagating on crest. The beam optics consists in a FODO lattice. The nominal values for the proposed source have been reported in Tab. 1.

The 10k macro-particles beam generated by PARMELA has been propagated through Linac1, Magnetic Compressor and Linac2 with the code ELEGANT. The correlated energy spread induced by Linac1 is 0.6% in order to compress the beam by a factor 6 in the 15 m long magnetic chicane with an R_{56} = 48 mm. At the exit of the Linac2 the required parameters for FEL operation have been achieved over more than 50% of the bunch length, as shown in Fig. 3.

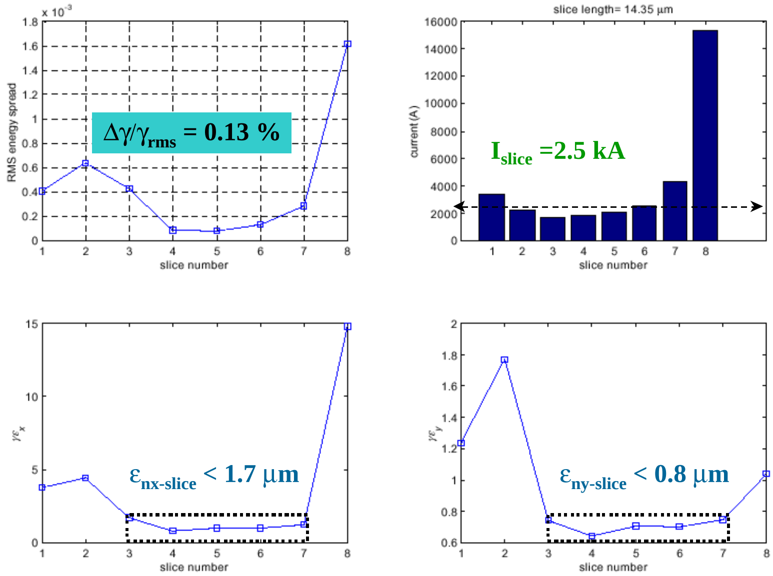

FIGURE 3. Energy spread, peak current and transverse emittances along the bunch.

A further improvement is expected by fully optimizing the compression scheme and by using a 4th harmonic cavity [4] for the linearization of the longitudinal phase space distribution.

THE FEL SASE SOURCE

We envisage using the same beam to feed two undulators whose characteristics are reported in Tab. 3. The characteristics of the FEL-SASE radiation up to the 5th harmonics, have been investigated by means of several codes: GINGER, GENESIS, MEDUSA, PROMETEO, PERSEO, and the results are shown in Tab. 4 and Fig. 4.

TABLE 3. Undulators characteristics

	Undulator 1 @1.5 nm	Undulator 2 @13.5 nm
Type	Halbach	Halbach
Period	3 cm	5 cm
K	1.67	4.88
Gap	12.67 mm	12.16 mm
ResidualField	1.25 T	1.25 T

TABLE 4. FEL-SASE expected performances

Wavelength (λ)	1.5 nm	1.5 nm
Saturation length	24.5 m	24.5 m
Peak Power	10^{10} W	10^{10} W
Peak Power 3¡ harm.	2 10^{8} W	2 10^{8} W
Peak Power 5¡ harm.	3 10^{7} W	3 10^{7} W
Brilliance 2	1.8 10^{31}	1.8 10^{31}
Brilliance * 3¡ harm.	10^{29}	10^{29}
Brilliance * 5¡ harm.	9 10^{28}	9 10^{28}

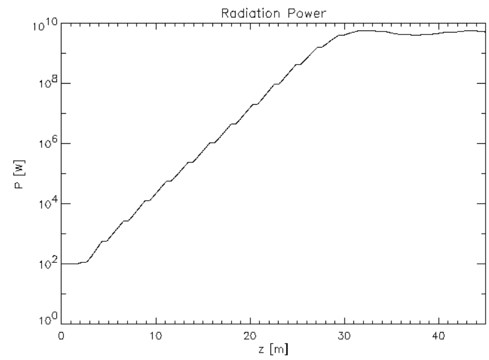

FIGURE 4. FEL signal evolution (λ=1.5 nm) along the undulator 2. The typical steps in the exponential rise are due to beam focusing regions where there are no undulators.

With the two undulators it is possible to cover a bandwidth from 1.2nm to 13.5nm, with the first harmonic, and a bandwidth from about 0.4nm to 4nm, using the 3^{rd} harmonic, which exhibits still a considerable peak power, as reported in Tab. 4.

Time dependent FEL simulations, performed using the particle distributions produced by the start-to-end simulations presented in previous section, are in progress, showing saturation for 50% of bunch slices after 30 m of active undulator length. These first preliminary results are encouraging and will be the starting point for further optimizations.

CONCLUSIONS

A preliminary start to end simulation of the SPARX proposal has been presented. The possibility to integrate an RF compressor into a linac for FEL application has been investigated for the first time. The 1 nC case with 120 MV/m peak field on the gun is also under investigation.

2 The brilliance is given in photons/sec/0.1%bw/(mm mrad)

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