SELF SEEDING CONFIGURATION AT SPARC

L. Giannessi, M. Labat, ENEA C.R. Frascati, via E. Fermi 45, 00044 Frascati, Italy
A. Bacci, INFN Via Celoria 16 20133 Milano, Italy

B. Spataro, INFN LNF Via E. Fermi 40, 00044 Frascati, Italy

Abstract

We propose an experiment of self seeding at SPARC. The experiment implementation requires only minor modifications of the existing SPARC layout. A self seeded FEL source presents several advantages such as a higher brightness preserving full wavelength tunability, compatible with the available reflecting mirrors, and a reduction of the demands in terms of electron beam parameters.

INTRODUCTION

Seeded FELs offer, in principle, several advantages with respect to self amplified spontaneous emission (SASE) [1-5] in terms of stability and coherence length and when the seed is combined with an undulator cascade, these advantages may be extended to the higher harmonics of the seed. Several schemes aiming at the generation of radiation at short wavelength combining the injection of an external seed and exploiting the harmonic generation process have been proposed at SPARC [6]. With the support of the European community and through the EUROFEL program, several components dedicated to the seeded operation have been implemented on the SPARC FEL. In particular a regenerative titanium sapphire laser amplifier has been installed and synchronized to the main photocathode drive laser and a magnetic chicane and a periscope (as shown in Fig. 1) allowing the superposition of an external light signal to the electron beam injected in the undulator array have been implemented. The external seed source is based on a chamber for the generation of high harmonics in gas (HHG) developed at CEA (France), which has been successfully tested at the end of 2007. Higher order harmonics of the TiSa regenerative amplifier generated in non linear crystals may be also used as seed to study configurations where high seed power is required and where the role of the FEL is that of non linear converter to shorter wavelengths. All these seed sources have a wavelength which is linked to the drive laser wavelength and can be tuned in a very limited range. An interesting alternative is that of using the FEL itself to generate the seed. The concept of the regenerative amplifier is well known in the community of solid state or gas lasers and the regenerative amplifier has also been proposed to reduce the linewidth of single pass FELs [7]. As it is shown in Fig. 2, after a first amplifier, much before saturation is reached, the electron beam which has undergone a mild modulation is sent to a dispersive section where the residual microbunching is cancelled. The radiation of the first amplifier is monochromatized and re-injected as a seed in the second amplifier.

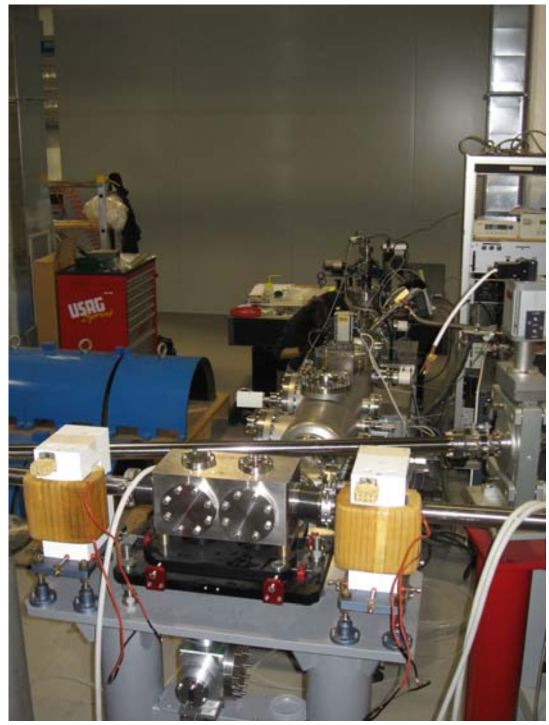

Figure 1: Detail of the magnetic chicane and of the injection periscope for the seeding experiment at SPARC.

The second amplifier operates as a seeded FEL and shows a reduced linewidth. The fluctuations of the input seed introduce a longitudinal shift in the saturation position but the saturation process dumps the amplitude fluctuations and the result is a reasonably stable source with an improved brightness with respect to a SASE amplifier. Such a scheme, which has not been implemented yet on any existing single pass short wavelength FEL, has been compared to a seeded FEL source showing in numerical simulations the capability of generating comparable or higher brightness than a HHG seeded FEL[8] while maintaining the full tunability of the FEL source. The main difficulty is the transport and matching of the electron and laser beams through their respective paths in the transfer line between the two amplifiers. At SPARC we don't have the possibility to implement the double amplifier scheme as shown in Fig. 2, but the injection periscope and the magnetic chicane for the seeding experiments can be used to implement the alternative scheme shown in Fig. 3 which has been also proposed for SPARX and may be used to characterize the behaviour of a self seeded FEL. At every drift between the undulator sections we have a diagnostic chamber where two mirror holders (per chamber) can be inserted in the beam path to extract the radiation. If one of these mirrors, e.g. in the last chamber after the sixth undulator, is a partially reflecting mirror, we may extract a fraction of the radiation from the FEL which may be used to seed a second electron bunch reaching the undulator about 120ns after the first. The injection can be done through the seeding periscope and the insertion of a monochromator in the optical path could be used to enhance the spectral purity of the source and to verify the source behaviour in presence of frequency selection.

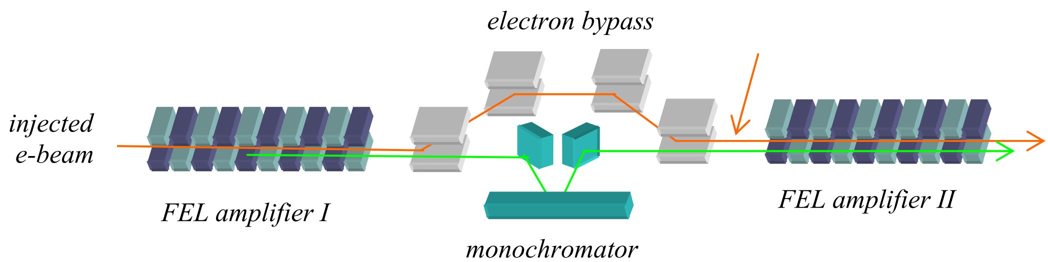

Figure 2: Layout of the Regenerative Amplifier FEL (RAFEL)

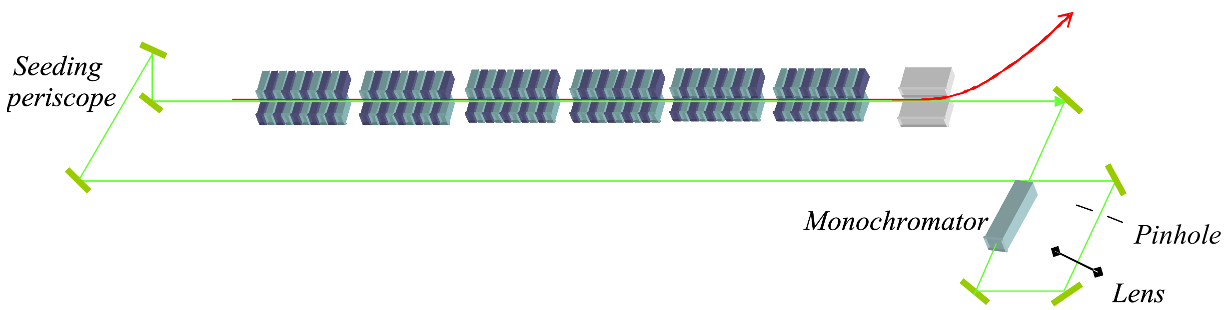

Figure 3: Experimental setup for self-seeding experiments at SPARC.

Despite the apparent simplicity of the scheme, there are some aspects which have to be addressed. An important issue is constituted by the energy jitter between the two pulses which have to fulfil the same resonance condition in the undulators. We have started the analysis of the device with FEL simulations for the two stage amplification in SPARC and performed preliminary calculations about the energy jitter in the multibunch operation, with the development of a code to calculate the interactions between the SLED (SLAC Energy Development) and a train of electron bunches.

SIMULATION OF SPARC IN A SELF SEEDED CONFIGURATION

In order to study this possibility at SPARC, we have modeled the SPARC self seeded amplifier in Perseo [9]. The simulation is set up as a time dependent SASE simulation for the first pass, where the electron beam shot noise initiates the laser process. After the first pass a fraction of the radiation field is filtered with a Gaussian filter of arbitrary width and is then re-injected for a second pass in the SPARC amplifier. Here we present an example based on the set of parameters of Table 1.

Table 1: Simulation Parameters

Electron beam		Undulator	
E	175 MeV	Period	2.8 cm
σ_E (rms)	2×10^{-4}	K	1.8
$\varepsilon_{x,y}$	1.5 mm mrad	Periods	6 x 75
I_{peak}	80A	Twiss β	1.8 m

The central resonant wavelength is 312.7nm. This parameter set in ideal conditions allows saturation already after the first pass. This can be observed in Fig. 4 (left), where the peak power vs. the longitudinal coordinate in the undulator is shown. We are assuming that 0.5% of the output radiation is filtered with a bandpass of 2×10^{-5} before the new injection in the undulator. Despite the small fraction of the power used to seed the second pass, the pulse reaches saturation after about 9m in the undulator (Fig.4, right). In Fig. 5 the spectra after the first pass (SASE) and the second pass at saturation are shown. The linewidth after the second pass is about one order of magnitude smaller than the natural FEL linewidth (0.22% is the bandwidth of the SASE signal at the end of the first pass).

#luca.giannessi@enea.it

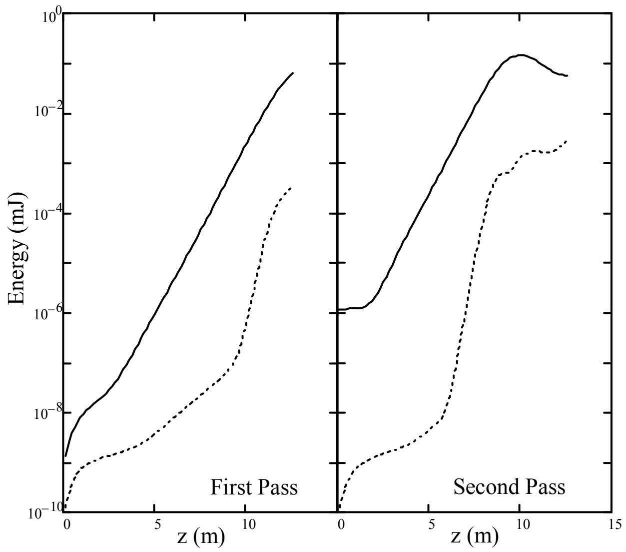

Figure 4: Power vs. the longitudinal position in the undulator in the first (left) and second pass (right).

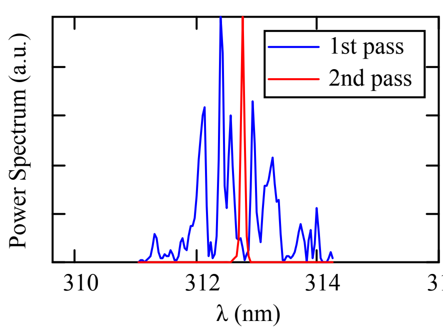

Figure 5: Power spectrum after the first pass (blue) and at saturation after the second pass (red).

The monochromatization process applied to the SASE signal after the first pass increases the shot to shot fluctuations associated to the nature of the SASE spectrum. Relative intensity fluctuations are proportional to $1/\sqrt{M_f}$ where M_f is the number of FEL SASE spectral modes contained in the filter bandwidth b_w. The number M_f is related to the FEL cooperation length $4\pi\rho/\lambda_u$ [10] by the relation $M_f = 4\pi\rho\, b_w \sigma_z / \lambda_u$ where σ_z is the e-bunch length, λ_u the undulator period and ρ the Pierce parameter. Fluctuations in the seed energy for the second pass are expected to scale with $1/\sqrt{b_w}$. The saturation length after the second pass, as a function of the filter width, is shown in Fig. 6. Each point is the result of the average over 50 simulations obtained with different random number sequences defining the startup shot noise. The error bars represent one standard deviation. The saturation length decreases with increasing filter bandwidth, corresponding to a higher seed energy. The fluctuations of the saturation length increase with narrower filter as a consequence of the input signal fluctuations (Fig. 6, top). The FEL bandwidth (Fig.6, middle) is smaller than the SASE bandwidth both at saturation (blue) and at the end of the undulator (red).

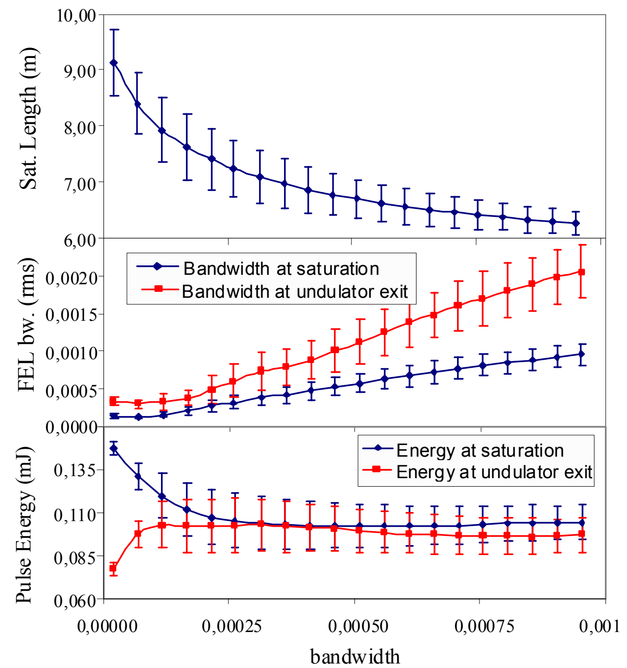

Figure 6: Saturation length (top), FEL bandwidth (middle) and pulse energy (bottom) as functions of the filter bandwidth.

In Fig. 6 (bottom) the pulse energy at saturation and at the end of the undulator vs. the filter bandwidth is shown. For values of b_w larger than $2.5\text{x}10^{-4}$ the output energy and the energy fluctuations are almost independent of the seed bandwidth b_w.

CALCULATION OF THE SLED-BUNCH TRAIN INTERACTIONS

The first issue that has to be addressed in the implementation of the above configuration, is the energy difference between the two electron bunches for the first and the second pass. This energy difference should be lower than ρ. The LINAC of SPARC operates with the SLED energy multiplier [11] which is needed to reach the nominal electron beam energy, from 150 MeV up to 200 MeV. The SLED enhances the RF peak power at the pulse length expense, without increasing the input power demands. In these conditions the final rf temporal profile shows a strong non-linear shape which causes that both the energy of the beam and its energy spread are strongly correlated to the injection phase of the RF pulse. The beam loading effect has also to be accounted for.

A code has been developed which takes the main design parameters (as the resonance frequency, structure length etc.) and some tracking parameters, as the electron beam injection phase into to the RF wave, the bunch length, the beam current and the distance between the bunches, and computes the final energy configuration of the electron beam, giving the energy difference between the bunches of the train, and the energy spread inside each one.

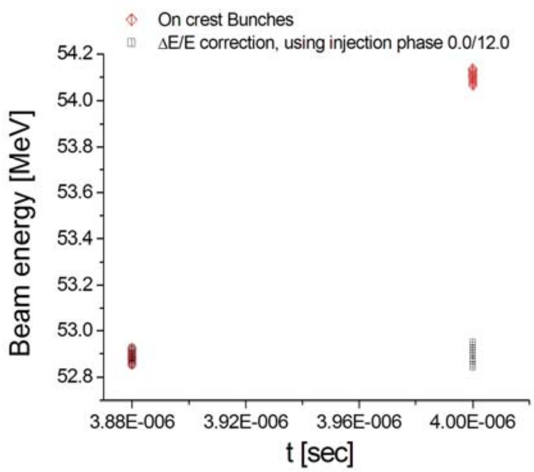

Figure 7: Train of two bunches spaced by 120 ns with a whole charge of 1.4 nC, before (red) and after (grey) the phase correction.

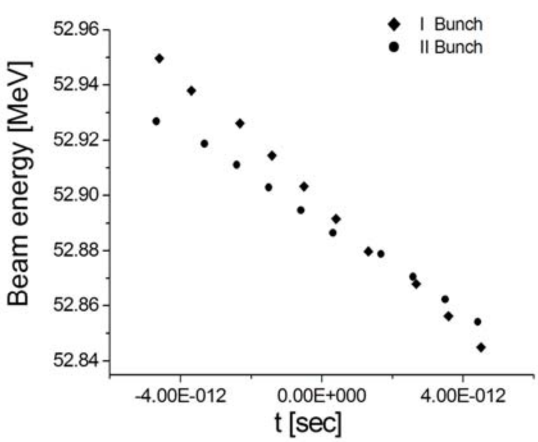

Figure 8: Intrinsic energy spread comparison of the bunches forming the train when the SLED energy jitter is turned off.

The ability to modify the injection phase of single electron bunches into the RF wave, gives the ability to null the energy jitter of two (or more) bunches into the train injected in the same klystron pulse. In Fig. 7 it is shown an example of the output of the code. The electron beam is composed by two bunches with a time separation of 120 ns. The whole charge is 1.4 nC. The final energy jitter, between the bunches, is corrected under the value of 0.5%, comparable with intrinsic energy spread of the single bunch.

The energy jitter between the two bunches is reduced from 2% without any phase correction, to less than 0.5% with an injection phase correction of 0.12°.

The code provides also information of the energy chirp in each bunch as shown in Figure 8. The results obtained so far support the possibility of synchronizing the two pulses for the self seeding.

CONCLUSIONS

We have presented a preliminary analysis of the feasibility of a regenerative amplifier based on the present SPARC layout. The idea of testing at visible/UV wavelengths the regenerative amplifier FEL improvements to the SPARC source shows a number of interesting features as:

- a higher brightness in wavelength in fully tunable conditions which could be obtained with the linewidth narrowing due to the monochromator,
- the double bunch scheme would allow an increase of the effective undulator length, doubling the gain per pass. This would allow the extension of the operation wavelength range in the UV (eventually VUV if an in vacuum optical transport is considered)

However we believe the most important aspect is the possibility to study, in a real high gain single pass device, the regenerative amplifier configuration, which could even be coupled with an input seed generated by the existing seed source. A number of aspects still need to be addressed, as the generation at the photoinjector level, of two low brightness electron bunches with the proper quality for driving a high gain FEL amplifier and will be addressed in future publications.

REFERENCES

[1] H.A. Haus, IEEE J. Quantum Electron. QE-17 (1981) 1427.
[2] G. Dattoli, A. Marino, A. Renieri, F. Romanelli, IEEE J. Quantum Electron. QE-17 (1981) 1371
[3] R. Bonifacio, et al., Opt. Commun. 50 (1984) 373.
[4] R. Bonifacio, et al., Phys. Rev. Lett. 73 (1994) 70
[5] E.L. Saldin, et al., Opt. Commun. 148 (1998) 383
[6] L. Giannessi et al. NIM A593 (2008) 132
[7] B. Faatz et al. NIM A 429 (1999) 125
[8] A. Marinelli, C. Pellegrini, L. Giannessi, MOOB05 these proceedings
[9] L. Giannessi, Overview Of Perseo, A System For Simulating Fel Dynamics In Mathcad Proceedings of the 2006 FEL Conference, www.jacow.org (2006) 91
[10] R. Bonifacio, L. De Salvo, P. Pierini, N. Piovella, C. Pellegrini, Phys. Rev. Lett. 73 (1994) 70.
[11] Z. D. Farkas at. al, SLAC-pub-1453, June 1974.