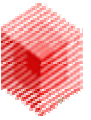


STATUS OF THE SEEDING EXPERIMENT AT SPARC



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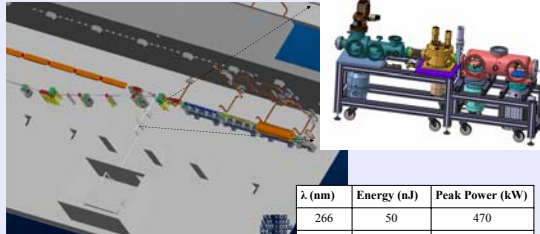
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During the last years, new schemes other than the Self Amplified Spontaneous Emission (SASE) have been proposed for reaching very short wavelengths in systems based on Free Electron Laser (FEL), where the main goal is to design relatively compact and fully tempo-rally coherent sources. Seeded FEL amplifier operation in combination with harmonic generation has been demonstrated experimentally in Brookhaven.

In this arrangement, an external laser source is seeded into a modulator, i.e. an undulator where a periodic energy modulation with the periodicity of the seed wavelength is induced in the longitudinal electron beam phase space. The successive beam evolution in a dispersive section induces the conversion of the energy modulation into a density modulation and consistent emission of radiation at higher order harmonics with longitudinal and transverse coherence reproducing those of the laser seed is obtained in a radiator undulator.

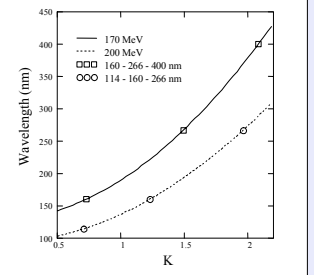
Important progresses in the field of strong laser-matter interaction have been made, leading to the generation of high-order harmonics of intense laser pulses in gases. This technique is being well controlled and the generation of radiation with reasonable energy per pulse down to 10 nm has been demonstrated. An in-tense tunable source as the High-order Harmonics of a Ti:Sa laser generated in a Gas (HHG), represents a good candidate to feed a FEL amplifier cascade with the final operating wavelength down to the water window range.



| λ (nm) | Energy (nJ) | Peak Power (kW) |
|----------------|-------------|-----------------|
| 266 | 50 | 470 |
| 160 | 5 | 47 |
| 114 | 0.5 | 4.7 |
| 88 | 0.5 | 4.7 |

Expected energy per pulse at the high order harmonics

Seeded SPARC FEL operating wavelengths



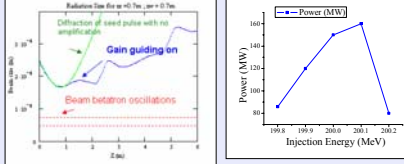
With these driving motivations a test experiment consisting in seeding the HHG harmonics in the SPARC FEL amplifier has been proposed and is under implementation. This experiment has many associated outcomes and possibilities:

- Study of the problems related to the injection of an external radiation seed in a single pass FEL. Analysis of the coupling efficiency of the e-beam – seed pulse in terms of the input parameters.
- The e-beam shot noise suppression induced by the coherent seed at different wavelengths can be studied. A comparison with simulation data will allow code validation for extrapolation to lower wavelengths.
- The evolution of phase/amplitude perturbations of a smooth pulse can be analyzed in different conditions of gain saturation and slippage. Strongly non-linear regime of FEL operation can be induced and experimentally verified.
- The above analysis can be extended to the harmonics produced in SPARC. The seeding in the present SPARC configuration is possible at 266, 160, 114 and 88 nm. At the shortest wavelength the FEL is operated exploiting the gain on higher order harmonics.
- The SPARC variable gap undulator can be operated at different resonant frequencies, thus allowing tests of cascaded FEL configurations. The fresh bunch injection technique, which has been considered as a mean to overcome the e-beam heating which inhibits the gain process in a multiple stage FEL cascade can be also tested.
- An experimental test of super-radiant FEL cascade can be implemented, and the properties of a Su-per-radiant pulse in a cascaded FEL can be experimentally studied.

Seeded FEL Dynamics An analysis of the seeded SPARC FEL characteristics has been performed with the code GENESIS 1.3. This code assumes a TEM00 Gaussian mode as input seed and solves the equations for the motion of the electrons and the evolution of the field in the undulator. What we observed is that the optical injection scheme does not critically influence the performances of the FEL amplifier, because when the exponential gain regime begins, the gain guiding of the electromagnetic power determines the equilibrium radiation beam size. For this reason the optimum point for the injection parameters consist in maximizing the intensity of the radiation in the first few gain lengths.

Summary of the seeded SPARC performances

| Resonant λ (nm) | Beam energy (MeV) | Power gain length (m) | Sat. length(m) (100 kW input Pow.) | Input power to saturate (W) |
|-------------------------|-------------------|-----------------------|------------------------------------|-----------------------------|
| 400 | 2.17 | 0.51 | 6.5 | 50 |
| 266 | 1.96 | 0.59 | 7.25 | 200 |
| 160 | 1.22 | 0.96 | 12 | $7.5 \cdot 10^3$ |
| 114 | 0.7 | 1.3 | 15 | 10^5 |



In a SASE FEL the resonant frequency is determined by the gain spectrum which depends on the input beam energy. A jitter in the input energy induces an equivalent jitter in the central radiation wavelength. In a seeded FEL a jitter in energy still induces a jitter in the gain spectrum but the central frequency is determined by the seed and the result is a fluctuation of the gain, which means a fluctuation in the saturation length and of the output intensity. This effect has been analyzed for the case with central resonant frequency at 266 nm. The simulations have been done in time dependent mode assuming a Fourier limited Gaussian seed pulse. This allowed to include the spectral broadening of the input seed associated to the pulse length (100 fs fwhm in this example).

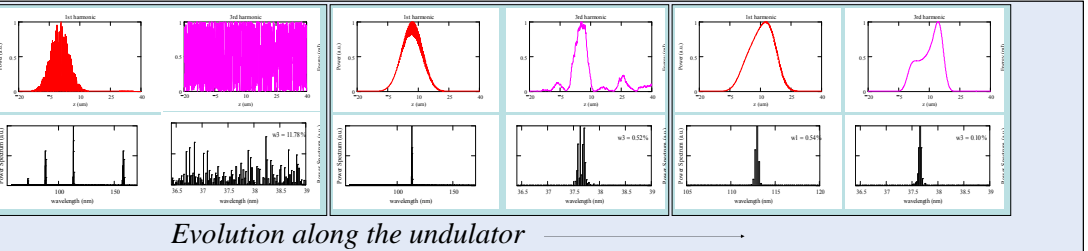
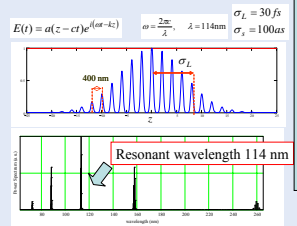
Beam dynamics The space charge effects associated to the magnetic chicane on the e-beam quality at the undulator entrance has been calculated with PARMELA and TREDI. The computations, that include the effect of beam space charge, were done for two beam energies, 155 and 200 MeV and two beam offsets, 5 and 10 mm. The chicane magnetic fields is set in order to get the desired beam deflection and simultaneously to control the e-beam centroid position and angle at the undulator entrance that must be kept within the prescribed tolerances (respectively 100 μ m and 50 μ rad). In the figure the x-z trajectory and the By magnetic fields of the chicane for a bump of 10 mm at an energy of 200 MeV is shown: the magnetic field on the first dipole is set to -400 gauss in order to get the necessary deflecting angle of 7.14 mrad while the magnetic fields of the inner dipoles must be equal (-800 gauss) in order to get a null angle in the mid-dipole while a magnetic field of opposite sign on the fourth dipole.

(in first approximation equal to the magnetic fields of dipoles 2 and 3) reports the beam on the axis. PARMELA gives, for a bump of 10 mm at 155 MeV, an emittance growth of ~3% in the bending plane due to a residual dispersion given by the combined effect of the space charge and the motion in the bending magnets. This emittance growth decreases to ~0.7% for a bump of 10 mm at 200 MeV. The results given by TREDI including CSR effects are similar. These results show that the injection scheme based on the use of a chicane in the SPARC transfer line for the seeding experiment does not give problems in terms of beam emittance and phase space matching at the entrance of the undulator.

Wake fields at the last mirror

The magnetic chicane deflects the electron trajectory of a distance between 5 and 10 mm from the undulator axis. The effects of the interaction of this beam with the last mirror inserted in the straight path has been analyzed. The mirror is modeled as a conducting block 6 mm large and 20 mm long. The wake potential induced by the SPARC beam x-z trajectory has been estimated according to the diffraction theory, with the ABCI code and including the effects of the asymmetries due to the vacuum chamber with the code MAFIA. In the latter case the maximum loss factor is ≈ 2 V/pC. The results show that the wake field effects on the beam dynamics can be neglected.

Seeding with HHG – Spectral filtering by slippage



Evolution along the undulator

Example of cascaded FEL with Fresh bunch injection technique

Several "seeded" FEL configurations can be explored.

As an example we show a simulation in which the segmented SPARC undulator is configured for Exploiting the fresh bunch injection technique

Beam energy 175 MeV
Peak current 100 A
Input seed 20 kW
Pulse length (rms) 100 fs

