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FEL DESIGN ELEMENTS OF SABINA: A FREE ELECTRON LASER FOR THz-MIR POLARIZED RADIATION EMISSION

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Abstract

SABINA, acronym of "Source of Advanced Beam Imaging for Novel Applications ", will be a self-amplified spontaneous emission Free Electron Laser (SASE FEL) providing a wide spectral range (from THz to MIR) of intense, short and variable polarization pulses for investigation in physics, chemistry, biology, cultural heritage, and material science.

In order to reach these goals high brightness electron beams within a 30-100 MeV energy range, produced at SPARC photo-injector, will be transported up to an APPLE-X undulator through a dogleg. Space charge effects and Coherent Synchrotron Radiation (CSR) effects must be held under control to preserve beam quality. Studies on beam transport along the undulator and of the properties of the radiation field have been performed with "Genesis 1.3" simulation code.

A downstream THz optics photon delivery systems has also been designed to transport radiation on the long path from the undulator exit up to user experimental area.

INTRODUCTION

SABINA is acronym of "Source of Advanced Beam Imaging for Novel Applications", a project that is in its early stage and will be deployed at the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati (INFN-LNF).

It aims at realizing a user facility delivering radiation with varying photon energy in the range 3-30 THz.

The main features of SABINA's will be:
1) a wide spectral extension (from THz to MIR); 2) a large pulse intensity up to mJ/pulse; 3) a short pulse duration ($< 10^{-12}$ s); 4) radiation with variable polarization.

A machine matching at the same time all these requirements, will represent a unique opportunity in the world-wide scenario.

THz radiation represents an interesting diagnostic tool in many fields of science such as: physics, chemistry, biology, medicine, cultural heritage recovery and security applications in food and pharmaceutical area [1].

In the specific case of SABINA, it is expected to use THz/MIR radiation for: 1) multicolour THz spectroscopy/imaging through the study of volumetric chemical composition maps; 2) spectroscopy/imagin for cultural heritage by means of high penetrations of THz radiation; 3) Imaging of biomedical tissue. In addition, THz/MIR radiation will allow pump-probe spectroscopy and chiral pump-probe spectroscopy on picosecond (ps) time scale, investigating the dynamical properties of exotic chiral molecules through the implementation of multiple colors and polarization.

The reference technology that will be implemented to generate radiation at SABINA, with the above features, is that of a single pass Free Electron Laser (FEL) amplifier [2]. The core of the SABINA's FEL will be the existing SPARC LINAC at the INFN-LNF. The radiation will be produced by an intense ultrarelativistic electron beam traversing an undulator based on the APPLE-X configuration which will allow to generate the radiation in the 3-30 THz range with linear, circular and elliptical polarization.

BEAM TRANSPORT ISSUES

To produce THz-MIR radiation the SABINA FEL will be feeded by the SPARC linac. The high quality (2 mm-mrad normalized emittance a few tenth per cent energy spread) and low energy (30 - 100 MeV) beams will be transported, through a dogleg, at the downstream undulator. A vacuum pipe of 4 mm inner radius and 5 mm outer radius will surround the electron beam all along its path.

The requirement of high brightness and low energy beams to drive the FEL implies a careful study of space charge effects on the beam degradation. In order to limit the space charge effects along the transfer line, a minimum beam energy of 30 MeV has been considered. The beam energy can be incremented up to 100 MeV in order to cover the whole spectral range up to the 30 THz of maximum frequency. Controlled space charge effects inducing an energy modulation of the beam before entering the undulator (pre-bunching) can boost the radiation emission process in the early stage of amplification in the undulator.

Particularly important is the study of the beam stability in the 'dogleg 'designeted to transport the electron beam from the linac to the undulator line. In fact it's well known in literature that space charge driven microbunching instablility (MBI) can occur at low beam energy, and that MBI can be significantly amplified by coherent synchrotron radi-

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ation (CSR) phenomena occurring in dogleg-like magnetic structures [3, 4]. Therefore possible detrimental effects on FEL performance must be monitored and the possibility of improving the FEL performances using these same mechanisms have to be investigated.

All these investigations require a careful analysis of the beam dynamics in the entire structure and simulations via GPT (General Particle Tracer) [5] are currently ongoing.

UNDULATOR

The resonant condition for an FEL emitting circularly polarized radiation at wavelength λ_r is:

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K^2\right) \quad (1)$$

where λ_u is the undulator period, γ is the electron beam energy in units of the electron rest energy and K it's the undulator parameter.

In order to reach the designed long wavelength, low beam energy and long undulator period are required. Since beam energy is restricted to the range 30-100 MeV as previously mentioned and because of physical constraints for which the total undulator length must be less than 4.5 meters, an undulator period of 5.5 cm has been set.

The undulator is divided in three modules of 1.3 meters each, separated by about 20 cm of drift space to allow the installation of holders for the vacuum pipe and beam position diagnostics BPM[1] . Magnetic correctors to handle the electron beam orbit will be placed externally, outside the undulator modules.

An additional constraint on the radiation properties required by the SABINA project is the generation of switchable left-right circular polarization. In order to accomplish this request, was proposed to use an APPLE[2]-type undulator which allows to produce vertically/horizontally linear polarized radiation and left/right-handed elliptical polarized radiation [6].

The chosen APPLE-X configuration has also the property of focusing the beam on both the horizontal and vertical planes, a feature not common to other variable polarization undulators based on permanent magnets as the APPLE II [7]. In this case the asymmetric focusing in the horizontal and vertical directions create problems in the optical transport of the beam, especially at low energy.

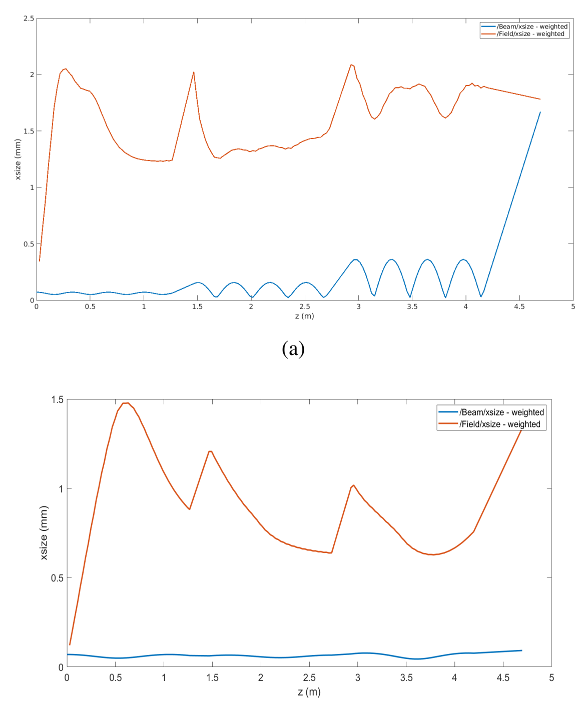
FEL SIMULATIONS

The analysis of SABINA FEL has been based on the software tool GENESIS 1.3 [8], a free available code developed by Sven Reiche (PSI). The simulations were focused on study the transport of particle and radiation beam through the undulator and the estimate of the divergence of the output radiation.

To run Genesis simulations, a preliminary field map study was performed[3] with RADIA software code [9] in order to determine the SABINA undulator magnetic field map informations that have then been used as Genesis input data. Several simulation runs were carried out, mainly focused on the endpoints of the operation range i.e. 10 µm and 100 µm radiation wavelength. In all cases the electron beam Twiss functions were set to satisfy the undulator matching conditions just like indicated in [10].

The RADIA simulations have shown that above 1 mm radius from undulator axis, non linear magnetic field components arise, resulting in a divergent trajectory for the electron beam. Genesis simulations have shown that in all set up the matched electron beams remain well below the 1 mm radius limit for the entire undulator length for both the beam centroid and its rms size if the electron beam matches the undulator axis at the undulator entry. Genesis simulations also showed that an offset of 100 µm from the undulator axis let us to transport the beam up to the undulator exit without detrimental results on beam dynamics and power growth.

In Fig. 1 rms size evolution in the x direction for both beam (blue) and radiation (red) along the undulator is shown for the 100 µm resonant wavelength case (a) and 10 µm resonant wavelength case (b). The simulated on axis beams met the matching condition for the first undulator section.



(a)

(b)

Figure 1: Genesis 1.3 simulations of beam (blue) and radiation (red) rms size along the undulator along x direction (the y direction is analogous because of APPLE-X symmetric focusing properties: (a) 100 µm radiation wavelength case; (b) 10 µm radiation wavelength case.

[1] Beam Position Monitor.
[2] Advanced Planar Polarization light emitter
[3] By A. Petralia, ENEA Frascati.

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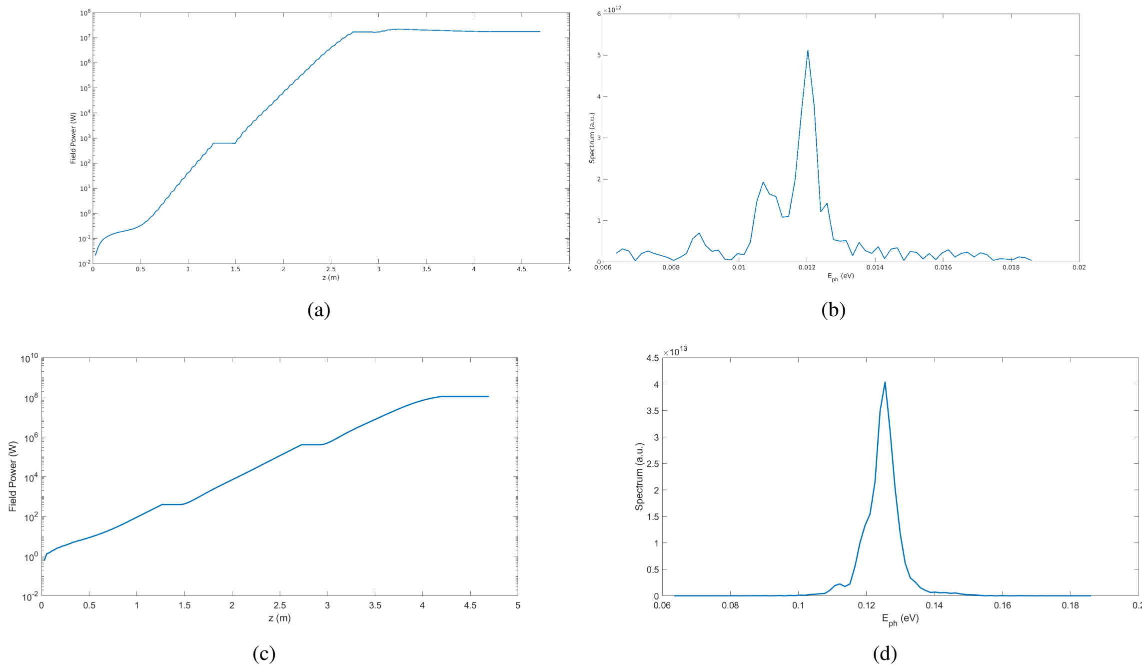

Figure 2: Power growth and radiation spectrum for 100 µm (a), (b) and 10 µm (c), (d) radiation wavelength cases.

From the radiation rms size we could estimate the radiation divergence at the undulator exit, which was used for the simulations of the THz transport and the definition of the relative optics downstream the undulator, in order to transport the radiation in the experimental area.

Figure 2 shows the simulation results for the power growth along the undulator and spectrum at the undulator exit for 100 µm and 100 µm radiation wavelength. The spectrum have the greater peak at the resonant condition, Eq. (1), and show secondary peaks as expected for a SASE FEL.

Finally analitical estimations was done aiming to verify which magnetic field 'error' we can afford along undulator line so that electron beam remains below the 1 mm limit from undulator axes: it turned out that a correcting coils around undulator or magnectic dipole correctors between undulator modules are required to correct Earth magnetic field effects on the beam.

CONCLUSION

FEL simulations of SABINA have been performed, showing comfortable results as concern beam dynamics along the undulator and output radiation properties. Other issues have to be study such as space charge effect and CSR on beam degradation. The possibility to exploit these phenomena for pre-bunching the beam upstream the undulator also must be investigated. Finally, since SABINA FEL will operate at relatively large wavelengths, a careful estimation of radiation power loss in the waveguide inside the undulator is worth to be performed.

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