EFFECT OF A QUASIPERIODIC UNDULATOR ON FEL RADIATION

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Abstract

The operation of conventional undulators results from an interference scheme in order to generate radiation of a fundamental wavelength and its harmonics. Whereas these harmonics are in most of the cases useful to reach higher energies, it is profitable in specific configurations to shift or reduce them, for instance to limit power on optics or to distinguish between one or two photon process in user experiments. This can be performed by so-called quasiperiodic undulators in which the periodicity of the magnetic field is destructed. In this case, the field amplitude is reduced on a few positions among the axis, inducing a destruction of the interference scheme. Such undulators are commonly used to generate spontaneous emission in synchrotron radiation facilities but could also be installed in Free Electron Lasers. The emitted radiation of the quasiperiodic undulator is compared with the usual configuration one, in the case of LUNEX5. Simulations using GENESIS code are described and results are discussed.

INTRODUCTION

Usually, a planar type undulator emits radiation on its fundamental and higher order harmonics. Several undulator schemes have been studied to enhance the high order harmonics intensity level in order to reach shorter wavelengths [1, 2]. Even though, in the hard X-ray region, high order harmonics are of great interest for intermediate energy storage rings, these harmonics which limit the signal to noise ratio in some experiments should be avoided in particular in the soft X-ray region when optical filtering of the spectral contamination is not possible. Quasiperiodic undulators have been proposed [3], enabling generation of pseudo harmonics with irrational ratios with respect to the fundamental radiation and a reduction of the intensity of the harmonics. The quasiperiodicity is achieved either in changing the length of magnetic field half period or the peak magnetic field in a suitable sequence. In consequence, the higher orders of the diffraction gratings of the beamline do not coincide anymore with undulator harmonics. Several systems have then been built [5] and radiation has been observed on NIJI-IV [6], ELETTRA [7], ESRF [8], BESSY [9], SLS [10] and SOLEIL [11]. A two-axis field quasiperiodic undulator has also been recently proposed [12].

Radiation properties of quasiperiodic undulators have been theoretically analysed for synchrotron radiation [13] and their interest for FELs mentioned in [14]. Indeed, FEL using quasiperiodic undulators appears to be quite interesting for user applications in order to discriminate between one photon process with harmonic radiation and multi-photon processes with the fundamental radiation. Nevertheless, to our knowledge, no dedicated study of analysis of single pass seeded FEL based on a quasiperiodic undulator has yet been performed. We here investigate it in the case of LUNEX5, an EUV seeded FEL project, comparing the radiation from a periodic and quasiperiodic undulator of 15 mm period.

THE LUNEX5 LAYOUT

LUNEX5 is a single pass FEL project which aims at the production of coherent synchrotron radiation with, in a first step, an electron bunch accelerated in conventional RF cavities up to 300 MeV. It is planned to work in the seeded configuration and two seeding schemes are considered: High order Harmonics in Gas (HHG) seeding [15] and EEHG scheme (Echo Enabled Harmonic Generation) [16]. More details on both schemes and there expected performances are given in [17]. For our study, we will focus on the HHG seeding scheme.

Electron Beam Parameters

The electron beam parameters of LUNEX5 are summarized in Table 1.

Table 1: Electron Beam Parameters of LUNEX5

Parameter	**Symbol**	**Value**
Energy (MeV)	E	300
Peak current (A)	I	400
Horizontal emittance (nm.rad)	ϵ_x	2
Vertical emittance (nm.rad)	ϵ_y	2
Relative energy spread (%)	σ_γ	0.02
Length (ps-rms)	σ_z	1

Undulator Parameters

The coherent radiation is produced in a long undulator, split into five independent sections. In the initial LUNEX5 design, the undulator is an in-vacuum planar hybrid undulator, with 15 mm periods and a periodic magnetic field of 0.86 T. Even if no quasiperiodic in-vacuum undulator have been built at SOLEIL, it is conceivable to realize such devices using a method similar to the one used for the APPLE-2 type undulators. Indeed, three APPLE-2 type quasiperiodic undulators have already been realized and installed for SOLEIL beamlines: one with a 64 mm period and three with an 80 mm period. The method to obtain quasiperiodicity on APPLE-2 type undulators consists in taking away from the undulator axis the Halback array's

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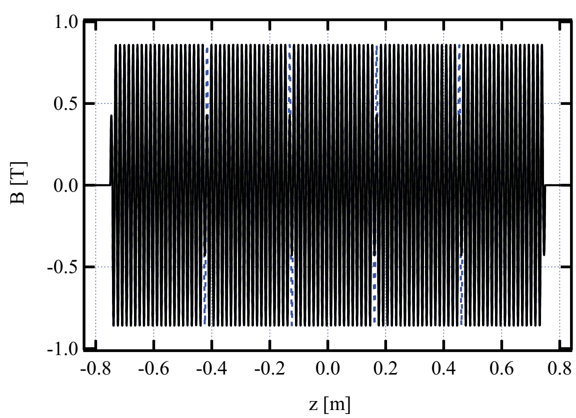
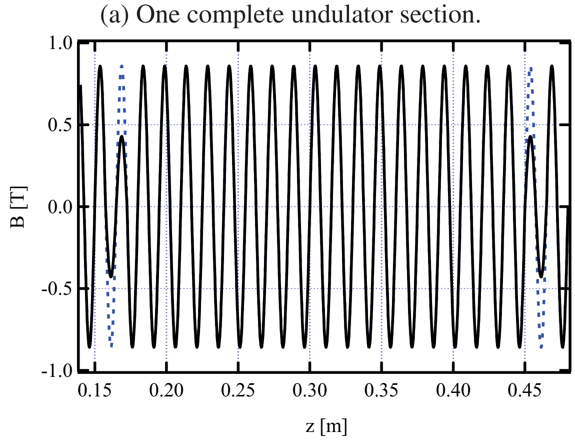
horizontally magnetized magnets of the four girders, at a few longitudinal positions. This displacement decreases locally the magnetic field amplitude on two consecutive peaks, resulting at first order in a trajectory offset of the electron beam without generating any angle kick. In order to avoid a final offset of the trajectory, two consecutive trajectory offsets should be of opposite sign, requiring that two consecutive displacements should be operated on magnets of opposite magnetization direction. For planar in-vacuum undulators based on a hybrid design, the displacement should then be applied on poles instead of magnets because they concentrate flux. Since a pole displacement induces a field modulation on only one peak, it is necessary to reproduce the operation on two consecutive poles to avoid kicks on electron beam angle.

To design the LUNEX5 undulator magnetic field, we proceeded as following. Using B2E [19] code, we generated a 200 periods perfect magnetic field and corrected its first and second integrals. This provides with the periodic magnetic field design. Four periods of this field are then artificially modified by dividing locally the magnetic field by a factor two, providing with the quasiperiodic field. The final magnetic fields, both in periodic and quasiperiodic configurations, are illustrated in Fig. 1 and the main parameters of the undulator sections are given in Table 2.



(a) One complete undulator section.



(b) Zoom on two sequences of lower magnetic field.

Figure 1: Undulator magnetic field: (—) quasiperiodic, (- - -) periodic. Calculation with B2E.

To maintain the electron beam matching along the sections, and therefore an efficient coupling between the electrons and the radiation, the electron beam is focussed periodically in a FODO lattice. The vertical focussing is ensured by the natural focussing of the undulator sections, and the horizontal focussing by quadrupoles inserted in between the undulator sections. The main parameters of the FODO lattice are also given in Table 2.

Table 2: Undulator Parameters for LUNEX5

Parameter	Symbol	Value
Number of undulator periods	N	200
Undulator period (mm)	λ_0	15
Magnetic field max (T)	B_M	0.86
Magnetic field min (T)	B_m	0.43
Number of sections	N_s	5
Drift between sections	D	1
Length of quadrupoles (m)	L_Q	0.15
Strength of quadrupoles (T/m)	F_Q	0.5573

SPONTANEOUS EMISSION CALCULATION

The incoherent radiation, i.e. the spontaneous emission, of one single electron wiggling in the undulator is first calculated using B2E code. Fig. 2 shows the spectra obtained in both periodic and quasiperiodic configurations. In the periodic case, the resonant wavelength is 38.17 nm. It becomes 37.9 nm in the quasiperiodic case, because of the reduction of the average magnetic field. The spectral shift is almost zero on higher harmonics, leading to irrational ratios, except for H3, with respect to the fundamental radiation (3 on H3, 4.96 on H5 and 7.43 on H7). The intensity on the high harmonics is also significantly reduced: by factor 1.2 on H3, 2.2 on H5 and 1.3 on H7, while only by factor 1.1 on the fundamental.

COHERENT EMISSION CALCULATION

The coherent emission is then calculated with GENESIS [18] also in both configurations. To define a quasiperiodic undulator under GENESIS, the value of the deflection parameter is given every half period. Since the electron beam is slightly kicked at each change of deflection parameter, as found previsouly with B2E, an odd number of half period is put in between each sequence of lower magnetic field. The deflection parameter along the undulator sections, in both periodic and quasiperiodic cases, used by GENESIS, is illustrated in Fig. 3.

The output power is then calculated in the steady-state mode on the fundamental and its harmonics up to the fifth order. In the case of a periodic undulator, the resonance wavelength is found at 38.16 nm. In the case of a quasiperiodic undulator, the resonance wavelength is slightly shifted and found at 37.95 nm. Both are in very good agreement

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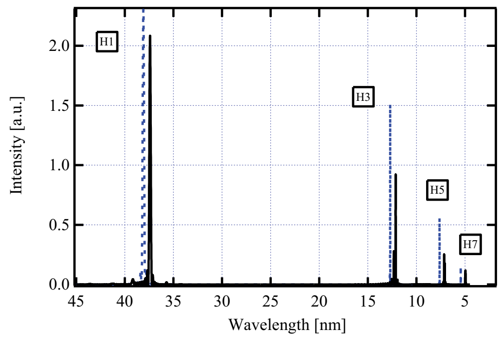
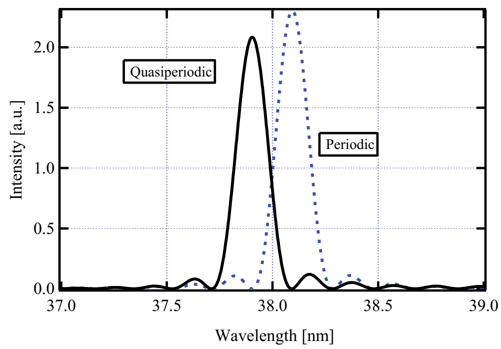


(a) H1 to H7. Scale for quasiperiodic shifted by -0.5 nm.



(b) Zoom on H1.

Figure 2: Spontaneous emission spectrum using one undulator section. Undulator magnetic field: (—) quasiperiodic, (- - -) periodic. Calculation with B2E. The other parameters are given in Table 1 and 2.

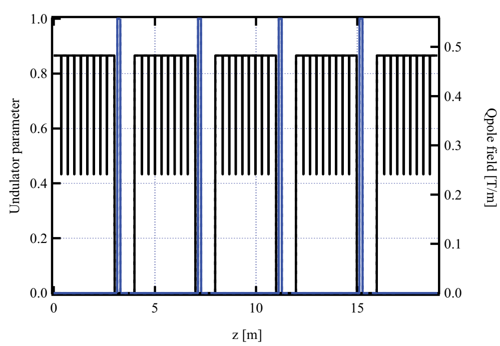


Figure 3: Undulator parameter AW (black): (—) quasiperiodic, (- - -) periodic. Quadrupole strength (blue). Calculation with GENESIS.

with the previous results. The resonance wavelength in the steady-state mode is found maximizing the output power on the fundamental as a function of the radiation fundamental wavelength. We confirmed this spectral shift by simulating the FEL in the time-dependent mode over one undulator section, as shown in Fig. 4.

As shown in Fig. 5, in both cases, the seed at 38 nm is efficiently amplified up to saturation within the five sections. The final output power on the fundamental is the same: about 0.1 GW. Differences appear on the harmonics. In the case of a quasiperiodic undulator, the output

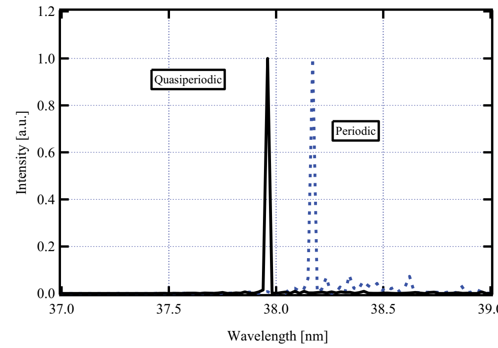


Figure 4: Normalized FEL radiation spectrum at the end of the first undulator section, using (—) quasiperiodic, (- - -) periodic undulator sections. GENESIS calculation in time-dependent mode. P_{seed}=100 W. The other parameters are given in Table 1 and 2.

power on the third and fifth harmonics is lower: 2.7 on H3, 10 on H5. The reduction of the harmonics intensity in the coherent case is slightly stronger with respect to the incoherent case. In addition, the harmonics exhibit a wiggling behaviour at the beginning of their exponential growth. The reasons of such behaviour are under study.

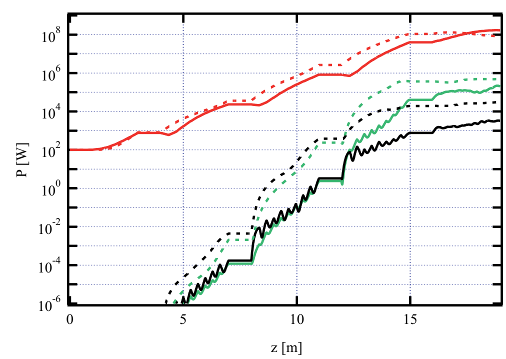


Figure 5: Evolution of the output power using (—) quasiperiodic, (- - -) periodic undulator sections. Calculation on the first harmonic (red), third harmonic (green) and fifth harmonic (black). GENESIS calculation in steady-state mode. P_{seed}=100 W. The other parameters are given in Table 1 and 2.

CONCLUSION

In the case of the LUNEX5 project, we studied the effect of a quasiperiodic undulator on the FEL radiation properties. In a first step, we gave a design of quasiperiodic magnetic field for a planar in-vacuum undulator. We then calculated and compared the undulator radiation with periodic and quasiperiodic configurations using B2E for incoherent radiation and GENESIS for coherent radiation. We found in both cases a slight offset of the fundamental wavelength and a decrease of the high harmonics intensity. It appears that the reduction of the high harmonics intensity is slightly

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more efficient in the case of coherent radiation. Investigations are carried on to further increase the spectral offset and decrease the intensity, of the high harmonics.

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