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BI-PERIODIC UNDULATOR INNOVATIVE INSERTION DEVICE FOR SOLEIL II

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Abstract

The Upgrade from the third to the fourth-generation light source of the SOLEIL synchrotron requires significant work on the reorganization of the equipment in the storage ring. Higher performance such as low emittance, small transverse size and high brightness are expected but requires redesigning the lattice. New constraints appear, requiring innovative designs of insertion device (ID) in order to keep the spectral range currently offered to users as large as today. The current straight sections can welcome two juxtaposed undulators to allow the beamline to cover a wide spectral range. However, the average space of straight sections dedicated to ID of SOLEIL II will be decreased in the future by 30%. SOLEIL Insertion Group studied several technical solutions combining two magnetic periods in a shorter space. Bi-periodic undulator project would make it possible to design a unique compact device with special magnet arrangement allowing to operate the ID alternatively with one periodicity to its triple value by means of longitudinal displacement of magnet arrays. Such an undulator enables to cover a wide spectral range of photons and only requires short space. A complete magnetic design with magnetic and spectral/optical performance will be presented and compared to usual solutions. Impact on the electron beam dynamics and magnetic forces will be also considered to have a complete knowledge on the feasibility of this project.

INTRODUCTION

The Synchrotron SOLEIL accelerates bunches of electrons to an energy of 2.75 GeV. It provides beams of photons in a wide range of energies from infrared to hard X-rays. As part of the SOLEIL II project, a modification of the existing installation will be carried out to optimize the production of photons. The storage ring will be redesigned to reduce electron beam emittance, increase photon beam flux and brightness, and improve beamline resolution. To achieve this optimization, the number of magnetic elements along the storage ring will increase considerably to focus the beam. This will result in a reduction in the length of the straight sections reserved for the insertion devices. On the beamlines, the wide ranges of photons presently proposed are obtained thanks to the longitudinal juxtaposition of two undulators with different magnetic periods. In order to maintain these energy ranges, engineers and technicians from SOLEIL are looking for viable alternatives to combine several magnetic periods on a smaller space. Studies have been carried out in other laboratories to make multi-periodic insertion devices in small space: Scientists of The Canadian Light Source have developed a system called "DUAL EPU Switchyard" [1] that allows lateral shifting of two undulators. This system permit to position one undulator on-axis of the beam and the second to be offset off-axis. The two EPUs covering two energy range of photons. The two undulators are arranged in a massive rigid structure. Studies have also been made at the Argonne National Laboratory by John Grimmer in the United States. "Revolver undulators" [2] have several independent magnetic structures of different periods arranged radially around the axis, allowing the period to be changed by rotation. In Germany, Pavel Vagin works on variable period helical undulator with tunable polarization [3]. This innovative system allow to modify the direction of the magnetization of the magnets by simple rotation. Consisting of two arrays of cylindrical magnets at fixed positions, huge amount of motors are needed for rotation of each magnet. These possibilities have been explored but the lateral footprint remains too important for certain beamlines and the unresolved constraints of the projects such as excessive motorization or excessive weight have made us prefer a new configuration. The Bi-Periodic undulator project presented in this report is an innovative and compact device allowing the use of two magnetic periodicities by superposition of magnets. This technique permit us to use half the space on the longitudinal axis (compare to two juxtaposed undulators) and to have no additional footprint in the transverse plane.

PRINCIPLE OF OPERATION

The Bi-Periodic project[1] is an undulator with variable gap and variable magnetic periodicity. It is a single insertion with a special arrangement of magnets allowing to switch from a magnetic period to its triple value by a longitudinal phase shift. The principle is based on a Halbach configuration: two series of parallel magnets separated by a gap allowing to concentrate the field lines in the gap and to obtain a sinusoidal magnetic field. The magnetic period λ_0 and the gap will have a direct impact on the magnetic field at the center of the undulator, which is directly related to the deflection parameter $K_i = 0.0934 \times B_i[T] \times \frac{\lambda_0}{i}[mm]$ (where B_i is the magnetic field content) and the energy range of the photons emitted $E_{fund}[keV] = 0.950 \times \frac{E^2[GeV]}{\lambda_0[cm](1+K^2/2)}$.

The Bi-Periodic undulator is based on the vertical superposition of two magnetic systems in the Halbach configuration. To alternate between the two periods, a phase shift system has been designed to obtain on the axis the cancellation of the vertical magnetic field of one period and the maximum value of the vertical magnetic field for the other period. Two operating modes are presented in Figure 1 and Figure 2.

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[1] Patent pending

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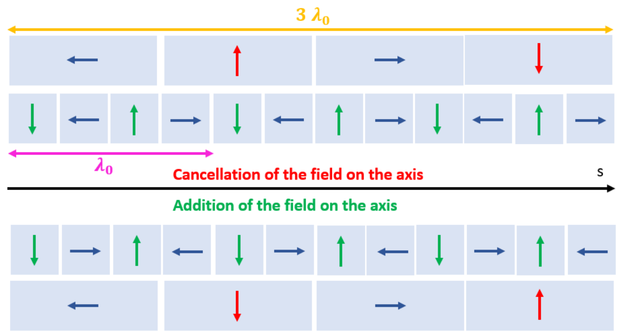

Figure 1: In phase 0, the magnets of the small period having a vertical magnetization are in phase (green arrows) while the magnets of the large period having a magnetization vertical are in opposition (red arrows): λ_0 period is selected.

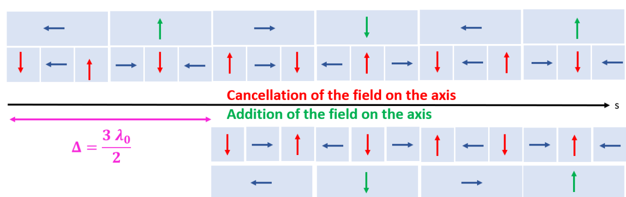

Figure 2: In phase $3\lambda_0/2$, the large period magnets with vertical magnetization are in phase (green arrows) while the small period magnets with vertical magnetization are in opposition (red arrows): $3\lambda_0$ period is selected.

This system therefore makes it possible to easily change the magnetic periodicity and to vary the magnetic field by varying the gap. Complementary spectral ranges are thus accessible. The system is advantageous due to its natural compensation of the forces of the magnets in opposition over the non-active period. This phenomenon of magnets repulsion of the inactive period and attraction of the active period makes it possible to relieve the mechanics by compensating part of the forces.

MAGNETIC DESIGN

Needs and constraints:

A study of the magnetic design was carried out using the RADIA program [4] (Python Version) taking into account the constraints related to the needs of the users. The goal is to verify the feasibility of the model and characterize the system by studying the magnetic fields produced. Characteristics of the undulator are presented in Table 1. A minimum gap has been imposed because of the vacuum chamber and the choice to study a 50 mm / 150 mm undulator was made because the spectral range corresponded to the needs of a potential beamline. A special geometry had to be used because of the proximity of the magnets and their interactions in order to guarantee good maintenance of the magnets. Planar and cross version are presented in Figure 3. Cross version imposed geometric constraints since it was necessary to be able to approach the axis of the four magnets simultaneously.

Table 1: Characteristics of the studied undulator.

Gap	g_{min} = 15.5 mm and g_{max} = 240 mm
Magnets	Permanent magnets NdFeB (B_r = 1.37 T)
Periodicity	λ_0 = 50 mm and $3\lambda_0$ = 150 mm
Geometry	Trapezoidal magnets
Versions	Planar version (Bz) Cross version (Photons polarization)
Energy range at 15.5 mm	λ_0 = 50 mm, B = 0, 564 T E_{fund} = 325 eV
	$3\lambda_0$ = 150 mm, B = 0, 501 T E_{fund} = 18 eV

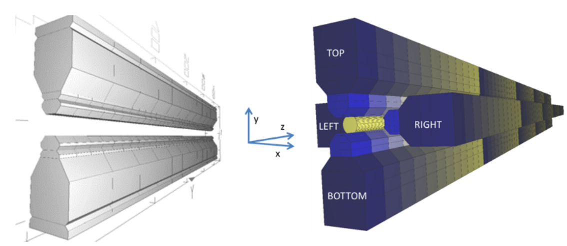

Figure 3: Planar Version (left) and Cross Version (right).

Main magnetic field and parasitic field:

A study of the theoretical magnetic fields is presented in Figure 4 and Table 2 to have more information on the shape and the maximum values of the fields.

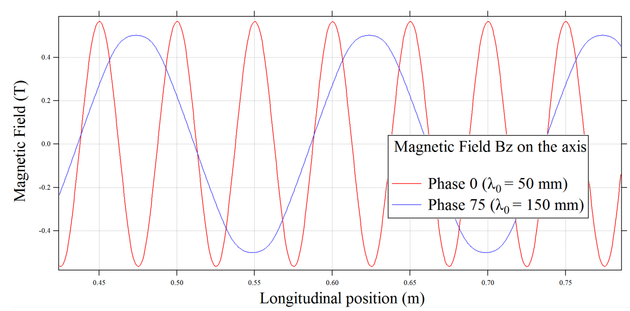

Figure 4: Magnetic field Bz on the axis at gap 15.5 mm.

Table 2: Maximum magnetic field simulated on the axis

Gap (mm)	14	15.5	17	20
Phase 0	0.638 T	0.564 T	0.499 T	0.391 T
Phase 75	0.523 T	0.501 T	0.479 T	0.437 T

The impact of the double periodicity and the appearance of the unwanted period on the field submitted to the electrons has been studied. The electrons not being concentrated in a single point, moving away from the magnetic axis $z = 0$ consists in moving closer to one of the two girders. The contribution of the parasitic period initially cancelled on the axis appears and compromises the cancellation of the magnetic field coming from the non-active period on the axis. This pollution is studied from +400 μm to −400 μm in Figure 5 and Figure 6.

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A Fourier Transform treatment was used in order to obtain the composition of the magnetic fields and the appearance of the parasitic period. The contamination could have an impact on the synchrotron radiation produced since it depends on the magnetic field perceived by the particle.

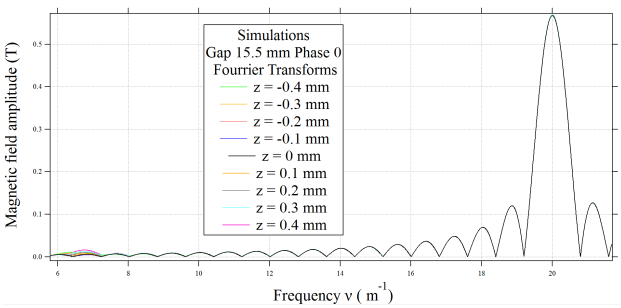

Figure 5: In phase 0, at the axis $z = 0$ we observe a peak for the frequency $\nu = 20$ m $^{-1}$ corresponding to the period $\lambda_0 = 50$ mm and an absence of frequency $\nu = 6.66$ m^{-1} corresponding to the period $\lambda = 150$ mm. At off-axis, frequency $\nu = 6.66$ m $^{-1}$ emerges and it remains low for this operating mode ($\Delta = 400$ µm : $\nu_{6.66} = 2.8\%\ \nu_{20}$). The large magnets being far from the magnetic axis, one approaches too slowly to have a significant effect on the spectrum.

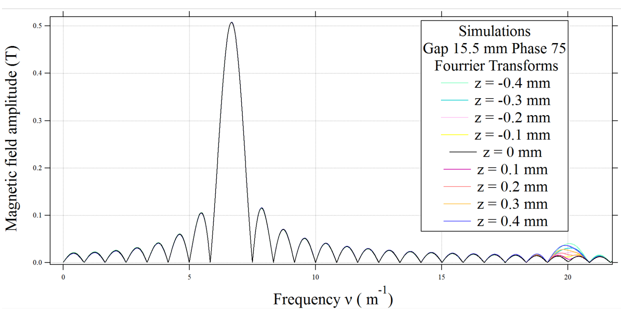

Figure 6: In phase 75, at the axis $z = 0$ we observe a peak for the frequency $\nu = 6.66$ m $^{-1}$ corresponding to the period $\lambda_0 = 150$ mm and an absence of frequency $\nu = 20$ m^{-1} corresponding to the period $\lambda_0 = 50$ mm. At off-axis, frequency $\nu = 20$ m^{-1} emerges and it remains higher for this operating mode than phase 0 ($\Delta = 400$ µm : $\nu_{20} = 7.9\%\ \nu_{6.66}$). The small magnets being near from the magnetic axis, the effect is therefore more visible.

Note that the vertical alignment beam is performed better than 100 µm corresponding to a maximum ratio of parasitic period of 1.09% for phase 0 and 2.26% for phase 75. The impact on the spectral distribution is negligible.

BI-PERIODIC PROTOTYPE

A prototype is being built in our magnetic measurement laboratory. Modules with three small magnets (period $\lambda_0 =$ 50 mm and average magnetization $M_{avg} = 1.38$ T) and one large magnet ($\lambda_0 = 150$ mm and $M_{avg} = 1.42$ T) were installed on an Apple II carriage allowing the phase shift and the variation of the gap. The prototype was assembled from NdFeB permanent magnets with a particular geometry which makes it possible to adapt to the mechanical constraints. The carriage is installed on a magnetic measurement bench equipped with a Hall probe and rotating coils.

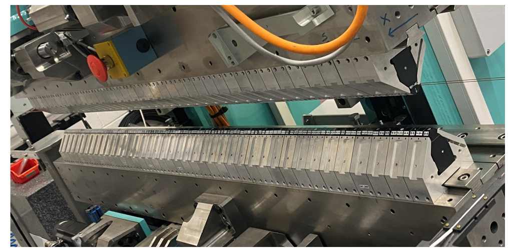

Figure 7: Bi-Periodic prototype.

Measurements were made at different gaps in the two operating modes. A comparison of the shapes and amplitudes of the fields was carried out between the measurements and the simulations. The overall behavior between the two is consistent: the shape of the magnetic field peaks evolves in the same way according to the different gaps, phases and vertical positions z. Localized magnetic defects were observed in measurements by seeing a variation of the peak fields along the undulator. A slight difference between the field values of the simulations and the average value of the fields produced by the prototype was also observed, with a difference of less than 3%. A shift in the magnetic axis between the simulations and the measurements was observed, a translation along z which can make think of a possible misalignment or bad calibration of the Hall probe. The results are encouraging because the measurements are consistent with the behavior observed on the simulations.

CONCLUSIONS AND PERSPECTIVES

The purpose of this study is to validate the concept of the bi-periodic undulator and to confirm its feasibility. With this results, a complementary study will be necessary to determine the synchrotron radiation produced from these magnetic field components and the impact of the parasitic coefficients on the radiation produced. These results are also currently used to determine the impact on the beam dynamics. The goal being to make it a real undulator, a study of the field terminaison for the end design was accomplish to correct the field integral and the trajectory of electrons. The prototype will be equipped with magnet terminaisons to keep the electron beam on axis and installed on the storage ring to study the impact on the beam dynamics and the characteristics of the photon radiation.

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