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BI-PERIODIC UNDULATOR: INNOVATIVE INSERTION DEVICE FOR SOLEIL II

Angela Potet*, Frédéric Blache, Pascale Brunelle, Marie-Emmanuelle Couprie, Carlos De Oliveira, Arnaud Mary, Thibaut Mutin, Amor Nadji, Keihan Tavakoli, Olivier Marcouillé
Synchrotron SOLEIL, France

Abstract

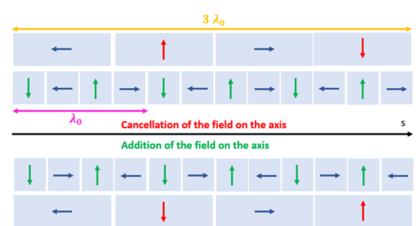
SOLEIL II project aims at optimizing the production of photons by a modification of the present facility. The storage ring will be redesigned to reduce electron beam emittance and as a consequence increase photon beam brightness. The number of magnetic elements will be increased and the space reserved for insertion devices will be decreased by 30%. Among solutions of undulators fitting in a smaller space while maintaining the full spectral domain, the innovative and compact Bi-Periodic undulator allowing the use of two selectable magnetic periodicities by superimposition of magnets. The magnetic period can be switched from one value to its triple value by mechanical shift of magnetic arrays. A magnetic design has been performed and the construction of a prototype, including magnetic measurements and corrections, is under progress. The magnetic fields, the radiation produced and the electron beam dynamics will be considered to have a complete knowledge on this undulator.

INTRODUCTION

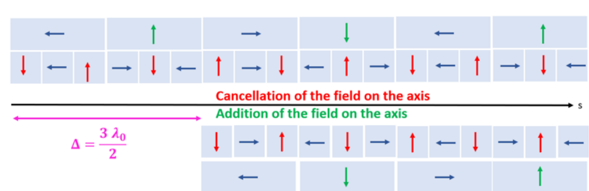
SOLEIL II [1] will lead to increase photon beam brightness. The storage ring presently composed of 16 cells and 3 straight section types will be redesigned to reduce electron beam emittance from 3.9 nm.rad to bellow 100 pm.rad. To achieve this reduction, the number of magnetic elements along the storage ring will be enlarged considerably. The consequence will be a reduction of the straight sections length reserved for the insertion devices. In present medium straight sections of 7 meters, the wide ranges of photons are obtained thanks to the longitudinal juxtaposition of two undulators with different magnetic periods. For the future ring, as straight section lenght is reduced to 4.2 or 3.7 meters, it will be impossible to iterate the same configuration to maintain the full spectral domain. Alternatives to combine several magnetic periods on a smaller space exist such as a dual undulalor with lateral shifting of two undulators [2], revolvers [3] with several indendepent magnetic structures of different periods arranged radially around the axis and a variable period helical undulator with tunable polarization [4] allows to modify the direction of the magnetization of the magnets by simple rotation of magnets. SOLEIL considers for its Upgrade DUAL, APPLE X [5] and BiPeriodic undulators. The Bi-Periodic solution is presented in this paper. This undulator is a device allowing the use of two selectable magnetic periodicities by superimposition of magnets. This technique permits to save half the longitudinal space previously required for SOLEIL I. The purpose of this study is to demonstrate the feasability of this system through simulations, construction of a prototype and tests on the present ring to validate its operation.

PRINCIPLE OF OPERATION

The Bi-Periodic undulator (Patent pending [6]) has a special arrangement of magnets allowing to switch from a magnetic period to its triple value by a longitudinal shift. It is based on the vertical superimposition of two magnetic systems in the Halbach configuration [7]. A system of magnets with a periodicity λ_0 is equipped vertically with an another array of magnets with triple periodicity $3\lambda_0$. This special arrangement of magnets enables to obtain two operating modes presented in Fig. 1. To alternate between the two periods, a phase shift system with a value of $3\lambda_0/2$ enables to obtain on the beam axis the cancellation of the vertical magnetic field of one period (red arrows) and the maximum value of the vertical magnetic field for the other period (green arrows).



(a) λ_0 mode



(b) $3\lambda_0$ mode

Figure 1: Configuration of magnet magnetization.

BI-PERIODIC PROTOTYPE DESIGN

The choice to make a design with a $\lambda_0 = 50$ mm period and its triple period of 150 mm was made to correspond to the needs of a potential beamline. NdFeB magnets were considered with a remanence of $B_r = 1.37$ T and a special trapezoidal geometry to facilitate the maintenance of the magnets on their supports.

* angela.potet@synchrotron-soleil.fr

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Undulator Terminations

As such a magnetic configuration disturbs the trajectory of electrons passing through the undulator, termination elements must be designed. These modules are used to reduce the integrals of vertical and horizontal fields generated by the undulator which induce displacements (modification of the position and the angle at the exit of the undulator). In addition to the very special magnetic environment of the undulator, the constraint of reusing the same magnets as for the main part was imposed for delivery delay reason. Figure 2 shows a short model of the Bi-Periodic undulator equipped with terminaisons at entrance and exit in order to minimize the shifts in angle and in position for the first mode (λ_0). After correcting the perfect undulator, the corrected values at the exit on the axis at gap 15.5 mm are: $\Delta x, \Delta z < 1$ µm and Δx', $\Delta z' \approx \pm 2.10^{-7}$ *rad* $\approx \pm 0.019$ G.m. When phase shift is applied, this correction is no more optimal but will be completed by the storage ring orbit correction system.

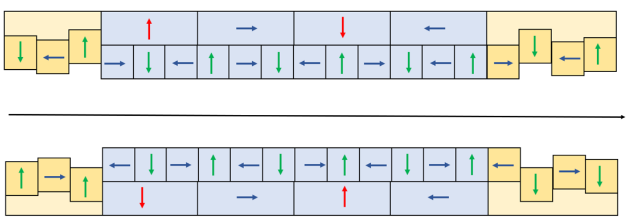


Figure 2: Configuration of magnets fot the λ_0 mode.

On Axis Magnetic Field

Magnetic design has been done using the RADIA program [8] (Python Version) to characterize the magnetic behavior of a perfect element with periodicity $\lambda_0 = 50$ mm et $3\lambda_0 = 150$ mm. One the axis, magnetic field was studied for the two operating modes at gap 15.5 mm (minimal gap allowed on the present storage ring), results are presented in Fig. 3.

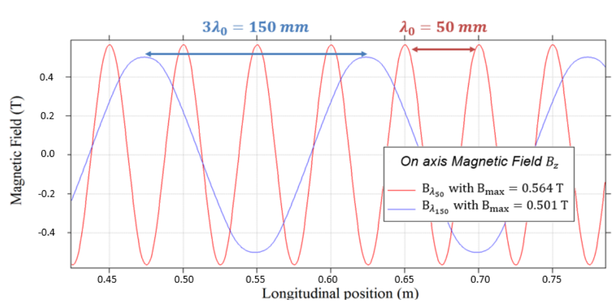
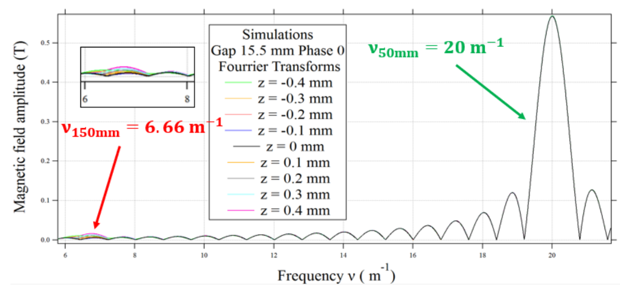


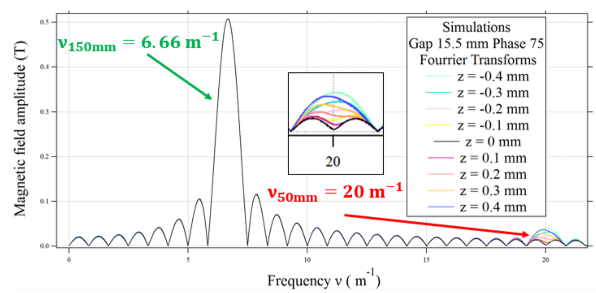
Figure 3: One axis magnetic field B_z at gap 15.5 mm: λ_0 mode in red (50 mm period appears) and $3\lambda_0$ mode in blue (150 mm period appears).

Off Axis Magnetic Field

The electrons that are moving away from the magnetic axis go closer to one of the two girders and the cancellation of the magnetic field coming from the non-active period on the axis is no more satisfied. The impact of a misalignment on the magnetic field components is analysed via the magnetic field harmonic decompositions for different values of vertical positions in Fig. 4. A Fourier Transform treatment was applied in order to obtain the harmonic content of the magnetic fields for a misalignement of $z = 400$ µm: frequency $\nu = 20$ m^{-1} corrresponding to the period 50 mm and frequency $\nu = 6.66$ m $^{-1}$ corresponding to the period 150 mm. In 50 mm mode: A misalignment in z would induce the appearance of the 150 mm period initially absent in this mode. At off-axis, frequency corresponding to the period 150 mm $\nu_{6.66}$ emerges up to 2.8% of the main frequency ν_{20} corresponding to 50 mm period. In 150 mm mode: A misalignment in z would induce the appearance of the 50 mm period initially absent in this mode. At off-axis, frequency corresponding to the period 50 mm ν_{20} emerges up to 7.9% of the main frequency $\nu_{6.66}$ corresponding to 150 mm period. Off-axis field harmonic composition can induce the appearance of the frequency related to the non-selected period of the mode and can have an impact on the emmited synchrotron radiation.



(*a*) λ_0 mode



(*b*) $3\lambda_0$ mode

Figure 4: Magnetic field harmonic composition.

Beam Dynamics

From the second order angle kicks, representing the impact of the undulator magnetic field on angle of electrons, are deduced the tune variation (see Table 1). For the present SOLEIL ring, using the RADIA field map in the TRACY3 code [9]: The impact on the closed orbit (< 1 µm) is acceptable and there is no reduction of the Touschek lifetime.

Synchrotron Radiation

The synchrotron radiation emitted by this undulator on the present storage ring was calculated for each mode. At gap 15.5 mm, for $\lambda_0 = 50$ mm mode the fundamental energy

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Table 1: Impact of magnetic field on betatron tune.

Period (mm)	$\Delta\nu_x$	$\Delta\nu_z$
$\lambda_0 = 50$	−0.0005	0.0020
$3\lambda_0 = 150$	−0.0010	0.0021

is $E_{fund} = 320$ eV and for $\lambda_0 = 150$ mm mode the fundamental energy is $E_{fund} = 18eV$. The study of the spectrum versus vertical and horizontal position is also in progress with Spectra Software [10].

BI-PERIODIC PROTOTYPE CONSTRUCTION

A prototype of this new undulator is in phase of developpment, to experimentally study this configuration and especially to identify the possible technical constraints. Check that the magnetic axis of the two systems are indeed the same and that only one of the two periods can be selected on the magnetic axis with no contamination of the other are of priority importance. The goal is to characterize the system on the bench and then install it on the present SOLEIL storage ring to validate its operation.

Aluminium modules composed of 4 magnets were installed on an carriage allowing the phase shift and the variation of the gap (Fig. 5). The length of this system is 1.5 m.

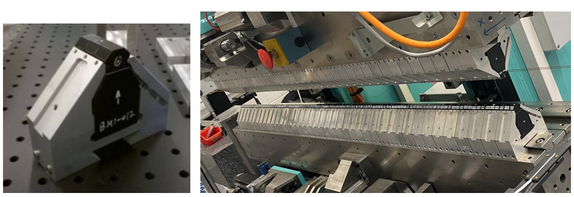

Figure 5: Module of magnets (left) and prototype installed on magnetic measurement bench (right).

Magnetic Measurement

An individual measurement of magnets delivered by the manufacturer (DAILYMAG) was made and average magnetization was deduced: for period $\lambda_0 = 50$ mm magnets average magnetization is $Br_{avg} = 1.38$ T and for $\lambda_0 = 150$ mm it is $Br_{avg} = 1.42$ T.

Magnetic measurements were performed on the prototype undulator to confirm the theoretical behavior. First of all, we calibrated the measuring bench equipped with Senis C-type Hall probe and flipping coil of copper wire. Measurements were made at different gaps in the two operating modes to compare the magnetic measurements to the simulations. Preliminary study of the magnetic field show that the general behavior of the field was identical, the shape of the magnetic field peaks and harmonic composition of magnetic field evolves in the same way according to the different gaps, phases and vertical positions z. Some differences were identified sush as difference between the simulated field and the measured field due to the magnetic defects of the magnets: the simulation fields are higher than the measured fields by 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 of the Hall probe. Magnetic measurements are underway to determine this magnetic axis and if this magnetic axis changes according to the gaps and the two modes of operation.

In parallel, support design of field terminaison modules was made and then built in our laboratories. The modules were then assembled on the undulator. A difference may appear between the simulation and the measurement so an additional correction using magic finger will be made to take into account the magnetic defects of the prototype.

CONCLUSIONS AND OUTLOOK

The first objective of a bi-periodic undulator is to replace two undulators by one which have the same spectral domain. In this purpose, a prototype has been designed and built to validate its operation and to identify the potential constraints. Present results are encouraging because magnetic measurement of prototype is in accordance with the simulations and we have possibility to select one of the two periods only. Magnet terminaisons to keep the electron beam on axis are installed. Magnetic correction will be finished to study the beam dynamics and the synchrotron radiation from the final measurements, to study impact of a misalignement on synchrotron radiation spectrum. Bi-Periodic prototype will be installed on the storage ring to study experimentally the impact on the beam dynamics and the characteristics of the photon radiation with a beamline. Following the theorical and experimental study of the Bi-Periodic prototype, cross version and APPLE X version are envisaged to produce soft X rays polarized photons for SOLEIL II.

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