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Comparison between measured and simulated X-ray flux from different undulators at SOLEIL

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Abstract. At SOLEIL, Insertion Devices (IDs) performances are first evaluated with the electron beam commissioning then by the study of the radiation properties with the beamline. Spectra calculated from magnetic measurements with Synchrotron Radiation Workshop code and the ones measured on the beamline are compared. Even and odd harmonics width are measured and spatial distributions at a fixed energy are checked for several gap and phase values. Radiation properties are detailed in the cases of a 20 mm period planar in-vacuum undulator ($U20$), a 42 mm period APPLE II device (HU42) and a 80 mm period APPLE II device ($HU80$) generating non periodic magnetic fields components.

1. Introduction

SOLEIL, the French synchrotron radiation light source, provides high intensity photons covering a wide spectral range by the use of a large variety of Insertion Devices (IDs) including in-vacuum and APPLE II undulators [1]. They are first assembled and optimized in laboratory before being installed and commissioned with the electron beam to compare field integrals and multipoles with magnetic measurements and to generate the feed forward tables from closed orbit distortion data. Then their radiation performances are validated by systematic comparisons of measured spectra on beamline and the one calculated from magnetic measurements using SRW [2]. In-vacuum undulators are planar hybrid structures generating only vertical field, whereas APPLE II undulators [3, 4] use four arrays of permanent magnets installed in a Halbach structure [5]. Arrays can be moved by pairs in parallel (resp. anti-parallel) mode to produce circular (resp. linear tilted) polarization with an adjustable gap. The resonant energy relationship of the n^{th} harmonic for these ID is given by :

$$E_n[keV] = \frac{9.5 \times n \times E_0^2[GeV]}{\lambda_u[mm] \times \left(1 + \frac{K_x^2}{2} + \frac{K_z^2}{2} + \gamma^2\theta^2\right)} \tag{1}$$

with K_z (resp. K_x) the deflection parameter in the vertical (resp. horizontal) plane, γ the normalized energy of the electron beam, θ the observation angle, E_0 the electron energy.

2. Magnetic measurements of IDs

The requirements for magnetic field quality are very tight because of the high number of IDs installed on third generation storage ring. The induced linear (closed orbit, focusing, chromaticity, emittance) and non-linear effects (lifetime, injection rate) on the beam [6] should be kept low while high radiation performances are expected in particular by achieving low phase error [7]. A rotating coil is used to perform transverse field integral measurements and multipoles correction with a reproducibility of 0.1 $G.m$, whereas the trajectory and phase errors are optimized on-axis thanks to a 3 axis Hall probe ($GH701$ from Bell) [8],with a reproducibility of 0.5 G and a spatial resolution of 1 mm as shown in figure 1.

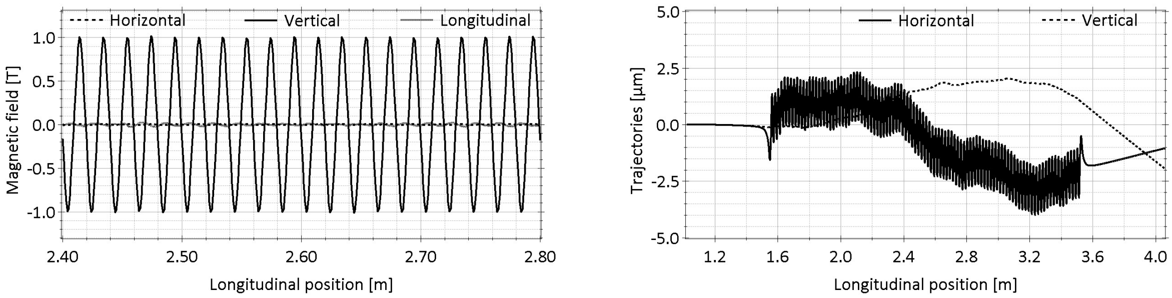


Figure 1. (left) On-axis magnetic field components measured with Hall probes and calculated trajectories (right) in each plane. Case of a 2 m long in-vacuum undulator, composed of 96 period of 20 mm, using Sm_2Co_{17} magnets with a remnant magnetization of 1.05 T and vanadium/permendur poles at minimal gap 5.5 mm.

3. IDs X-ray simulations and beamline measurements

SRW [2] is used to compute the synchrotron radiation emitted by relativistic electrons crossing a magnetic structure in the near or far field range, taking into account finite emittance, energy spread and the optics of the machine. Radiation calculation are performed directly from magnetic measurements for several gap and phase values. Once installed the radiation propagation axis of the ID is checked with an home-made detector, called DiagOn (Diagnostic of Undulators) [9], showing the spatial distribution of the photon flux at a fixed energy.

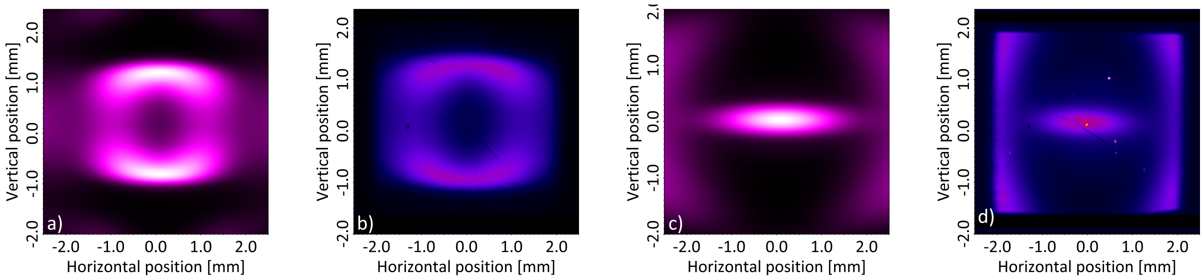
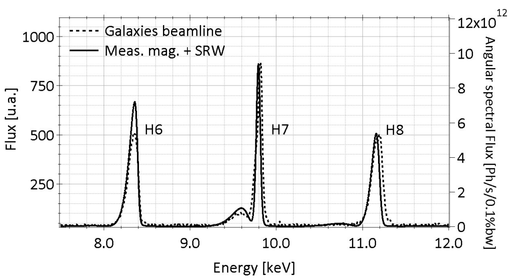


Figure 2. Expected DiagOn images calculated from magnetic measurements using SRW (a-c) and the experimental ones measured on beamline (b-d) at gap 22.5 mm (a-b) and 35 mm (c-d). Case of a 1.6 m long APPLE II undulator, composed of 38 periods of 42 mm (HU42), using $Nd_2Fe_{14}B$ magnets with a remnant magnetization of 1.22 T in linear horizontal polarization. DiagOn energy fixed at 2.780 keV and observed on a 5 × 4 mm window at 13.25 m from the source. Calculations performed using a 2.75 GeV electron beam at 400 mA, with an energy spread value of 0.1025 %, a vertical emittance of $3.9e^{-11}$ $m.rad$ and an horizontal one of $3.9e^{-9}$ $m.rad$.

Figure 2 presents the comparison of the calculated spatial distribution versus experimental DiagOn images of a 42 mm period APPLE II undulator ($HU42$). Figures a and b shows the third harmonic, it appears as a ring because of its resonant photon energy differs from the DiagOn selected energy (off-axis emission). In figures c and d the fundamental appears as an on-axis peak because its resonant photon energy coincides with the DiagOn energy. A rather good qualitative agreement is found on the images between SRW calculations from magnetic measurements and the experimental ones. Quantitatively, the diameter of the theoretical ring is 1.99 mm with a full width at half maximum (FWHM) 0.54 mm, whereas the measured one is 2.21 mm diameter with a FWHM of 0.4 mm (in Fig. 2a.b) and the vertical size of the theoretical spot is 0.43 mm and 3.08 mm in horizontal, whereas it has been measured 0.32 mm in vertical and 2.81 mm in horizontal (in Fig. 2c.d). Discrepancies between calculations and measurements are probably due to the estimated pixel size and Hall probe calibration.

Then for each gap and phase couple, a special alignment of the beamline is realized by setting the monochromator to an energy slightly higher than the resonant one and scanning vertical and horizontal slits to reach a maximal flux in both planes. After a correct alignment of the beamline on the emitted photon beam, the monochromator scans a range of energies while the radiation is collected by a calibrated photodiode as shown in figure 3 (left) for a 20 mm period in-vacuum undulator ($U20$). Odd harmonics appear more intense than the even ones, confirming a proper alignment of the undulator magnetic axis with respect to the beamline. Even harmonics are growing due to the emittance value, as the aperture is very small. The contribution of the emittance term (so-called in-homogeneous broadening) becomes more important with respect to the natural bandwidth (homogeneous one) as the harmonic number increases. The large slope on high energy side of odd harmonics results from the natural bandwidth ($\frac{1}{n \times N}$, with n the harmonic number and N the number of period composing the ID) and the energy spread while the reduced one on low energy side is dominated by the electron emittance and the observation aperture. The bump which appears on the low energy side of the 7^{th} harmonic is a sign of the emittance effect [10], resulting from the $\gamma^2\theta^2$ contribution as expressed in equation 1. Figure 3 (right) shows that the expected bandwidth between 2 keV and 12 keV for odd and even harmonics is in good agreement with the one measured. All the more that differences in bandwidth measured values ($\approx$ 11 eV on $H5$) are mainly due to the step in energy during the measurement which was 2.5 eV.



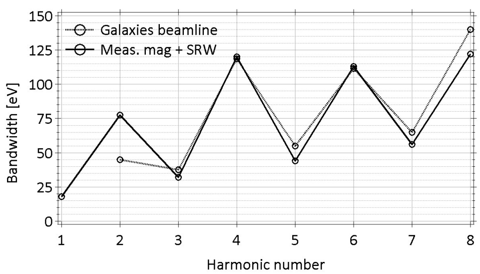


Figure 3. (left) Comparison of the 7^{th} harmonic of the spectral flux between SRW calculations from magnetic measurements (plain line) and the beamline measurements (dash line), observed through a 100 $\mu m \times 100$ μm aperture at 11.7 m. Case of the in-vacuum undulator of figure 1. Calculations performed using electron beam parameters of figure 2. (right) Comparison of the bandwidth at half-full maximum of each harmonic.

The same measurements have been performed on a 80 mm period, quasi-periodic APPLE II device. Contrary to periodic undulators, quasi-periodic ones generate non integer harmonics (called "irrational harmonics") leading to a reduced harmonic contamination for the beamline [11] after monochromator selection. The quasi-periodicity of the magnetic structure is obtained by vertically shifting four magnets on each array.

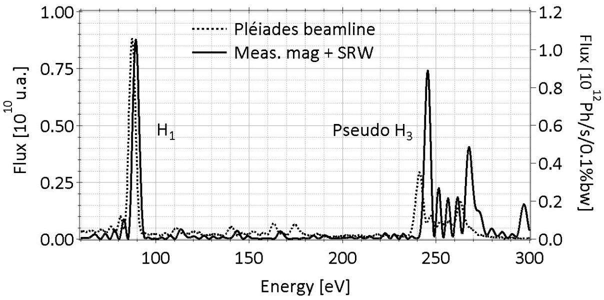


Figure 4. Comparison of the 1^{st} and pseudo 3^{rd} harmonic of the angular spectral flux between SRW calculations from magnetic measurements data (plain line) and the one measured on the beamline (dash line), observed through a 100 $\mu m \times 100$ μm aperture at 13.09 m from the source. Case of a 1.6 m long quasi-periodic APPLE II undulator, composed of 19 period of 80 mm (HU80), using $Nd_2Fe_{14}B$ magnets with a remnant magnetization of 1.22 T, at gap 20 mm in linear vertical polarization. Calculations performed using electron beam parameters of figure 2.

As shown in Fig. 4 and expected from calculations, the third harmonic is shifted and divided into several little adjacent peaks due to the aperiodicity and the high K value of the ID ($K_x = 5.678$ and $K_z = 7.397$). The energy of the fundamental measured on the beamline is 2 eV lower than the predicted one, this shift may be due to a combination of a slight error on the ID alignment and uncertainties on the Hall probe calibration resulting in a lower magnetic field measured value than real one. The measured bandwidth of the fundamental corresponds to the calculated one whereas there is 1 eV of difference on the pseudo-third harmonic.

4. Conclusion

We have checked three types of IDs installed at SOLEIL (in-vacuum, APPLE II and quasi-periodic APPLE II) in terms of angular spectral flux and spatial distribution of the photon flux. SRW calculations from magnetic measurements data are in a rather good agreement with the beamline measurements for several polarizations on all these IDs, which implies that magnetic measurements of SOLEIL IDs provides confident results.

References

[1] Couprie M E *et al.* 2007 *Nucl. Instr. and Meth. in Phys. Res.* **575** 33
[2] Chubar O and al 2002 *Optical Engineering* **4769** 145
[3] Sasaki S *et al.* 1992 *Japan Journal of Applied Physics* **31** 1794
[4] Sasaki S 1994 *Nucl. Instr. and Meth.* **347** 83
[5] Halbach K 1980 *Nucl. Instr. and Meth. in Phys. Res.* **169** 1
[6] Brunelle P *et al.* 2008 *Proceedings of European Particle Accelerator Conference, Genoa, Italy* 2097
[7] Walker R P *et al.* 1989 *Particle Accelerator Conference, Trieste*
[8] Frachon D 1992 *PhD thesis, Université J. Fourier, Grenoble*
[9] Desjardins K *et al.* 2008 *Nuclear Science Symposium Conference Record*
[10] Elleaume P *et al.* 2003 *Undulators, wigglers and their applications*
[11] Sasaki S 1995 *Physical Review* **52** 5454
[12] Batrakov A *et al.* 2006 *9th Conference on Synchrotron Radiation Instrumentation*
[13] Marcouillé O *et al.* 2006 *9th Conference on Synchrotron Radiation Instrumentation*
[14] Couprie M E 2012 *Future Light Sources Conference*