DEVELOPMENT OF A SHORT PERIOD HIGH FIELD APPLE-II UNDULATOR AT SOLEIL

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Abstract

At SOLEIL, the production of high brilliant photon beams with adjustable polarization, in the VUV soft X-Ray range, is often achieved by means of Advanced Planar Polarized Light Emitter-II (APPLE-II) undulators. Following the request of the new SIRIUS beamline for an undulator providing circularly polarized radiation in the 2 keV to 5 keV range, and planar radiation up to 10 keV, we designed an HU36 which is a 2 m long APPLE-II type undulator with 36 mm period and 0.75 T peak field at a minimum gap of 11 mm. High harmonic radiation (up to the 13^{th}) is required to reach the high energy domain; therefore a small RMS phase error is needed. However, due to the small period and larger field, the magnet supports, commonly used at SOLEIL to hold the magnets on the girders, have shown some deformation due to the large magnetic forces, resulting in unacceptable variations of field integrals as the shift between girders changes. Solutions to minimize these errors are discussed and finally the HU36 magnetic performances are reviewed.

INTRODUCTION

SOLEIL is a 2.75 GeV energy third generation light source located in Saint-Aubin close to Paris [1]. Short period high field Insertion Devices (ID) such as in-vacuum undulators [2] and more recently cryogenic permanent magnet undulators [3] are of primary interest to produce hard X-rays, but with only linear polarization. Elliptically polarized undulators (EPU) with short period and high field are also required when an X-ray source with adjustable polarization is desired.

Among the different EPU technologies, the APPLE-II one enables to produces the strongest helical field [4]; it was hence the natural candidate to produce short period high field EPU. APPLE-II ID consists in two planar undulators side by side; the adjustable longitudinal shift between the girders sets the polarization.

At SOLEIL a short period (36 mm) high field (0.75 T peak field) EPU is under development, it has a 36 mm period and 0.75 T peak field. This ID should provide to the SIRIUS beamline a continuous X-Ray beam ranging from 2 keV to 5 keV with adjustable polarization and up to 10 keV with horizontal polarization.

HU36 DESIGN

Magnetic design

The 3D magnetostatic software RADIA [5] was used for the calculation of the magnetic field of the 36 mm period APPLE-II undulator. The main characteristics of the magnet blocks are presented in Table 1. Fig. 1 displays the on-axis horizontal and vertical peak field versus the undulator gap for different shifts in terms of the undulator period λ..

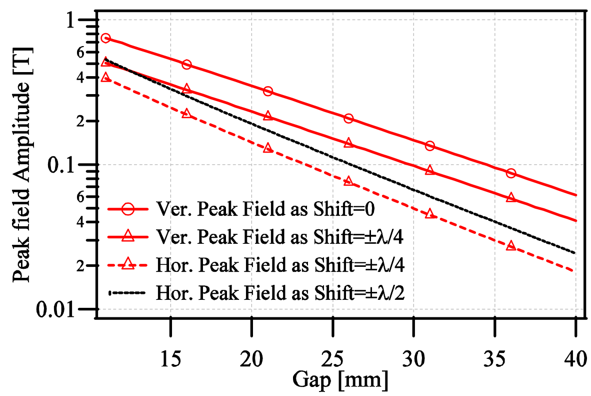

Figure 1: HU36 peak field versus undulator gap

Table 1: Magnet block specification

Width	Height	Length	Remanence	Coercive field
32 mm	32 mm	9 mm	1.22 T	2.35 T

Closing the gap as low as 11 mm without reducing the beam vertical aperture is only feasible in the Short Straight Section (SDC), usually dedicated to in-vacuum undulators. So far at SOLEIL, the standard NEG-coated narrow gap chambers for in-air 5 m long ID straight sections has a thickness of 13 mm [6] so that the usual minimum gap of in-air ID is fixed at 15.5 mm. Therefore a dedicated 2 m long chamber based on the ESRF NEG-coated narrow gap chamber design with a 10 mm [7] has been manufactured. The vacuum chamber is already installed on the SDC15.

The large H Beta functions in SDC (β_x=17.78 m and β_z=1.75 m in the middle of a SDC) limits the integrated field error of the HU36 to values listed in Table 2. For comparison, the maximum admitted values are given for an HU44 APPLE-II installed in a medium straight section (SDM, β_x= 4 m and β_z= 1.77 m in the middle the section).

Table 2: Maximum integrated field errors tolerances

	HU36	HU44
Horizontal/ Vertical Dipole [Gm]	0.2/0.2	
Normal/Skew quadrupole [G]	±20/±50	±60/±90
Sextupole [G/m]	1500	8400

Spectral performance

The spectral flux has been computed with the Synchrotron Radiation Workshop (SRW) software [8].

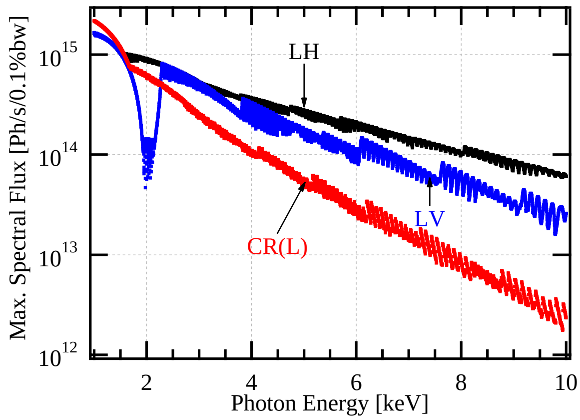

Figure 2: Maximal spectral flux in linear horizontal, linear vertical and circular polarization through an aperture of 2 mm (h) x 0.8 mm (v) at 11.7 m (0.17 mr x 0.068 mr) optimized with respect to the gap and the shift between magnet arrays for each photon energy.

Mechanical design

The mechanical design of the SOLEIL APPLE II type undulator [9] comports magnets mounted on independent holders into modules which are fixed via a dovetail onto the four girders. The girders are connected to a motorised carriage which enables gap motion and shift between girders.

Magnet holders are grouped by 3 or 5 into modules so that the module field integral arises from magnetic errors. In addition, the arrangement of the modules allows each type of module to be positioned on any girder.

All materials except the magnets must be amagnetic to avoid hysteresis with respect to gap and phase changes. Massive mechanical modules pieces such as magnet holder are in aluminium while the magnet clamps are in stainless steel. In addition, the modules are carefully designed to limit any magnet motion due to magnetic forces. For the HU36 undulator the maximum value of the magnetic force was expected to be as high as 100 N in each direction. A first ANSYS [10] computation showed that a magnet holder mainly deflects along the longitudinal axis by typically 20 µm under a longitudinal force of 100 N [9]. This deflection was considered as acceptable.

HU36 CONSTRUCTION

HU36 assembling and shimming

The HU36 was assembled and corrected following four steps already used to produce the 9 APPLE-II installed on the storage ring:

- Assembling of the magnets into modules.
- Assembling of the modules on the jaws.
- Shimming by magnet displacements.
- Shimming by "Magic Fingers".

All these process are managed using IDbuilder, a multi-parameter genetic algorithm developed at SOLEIL [11]. In particular during the shimming process with magnets displacements the integrated field errors are corrected at several phase and/or gap values. In practice we perform such optimization at the minimum gap and with phase shift values, $-\lambda/2$, $-\lambda/4$, 0, $\lambda/4$ and $\lambda/2$. The maximum value (over all 5 phase shifts) of the integrated multipole components versus the shimming iteration is displayed in Fig. 3 a, b and c. The RMS phase error at a null phase shift versus the shimming iteration is reported in Fig. 3 d.

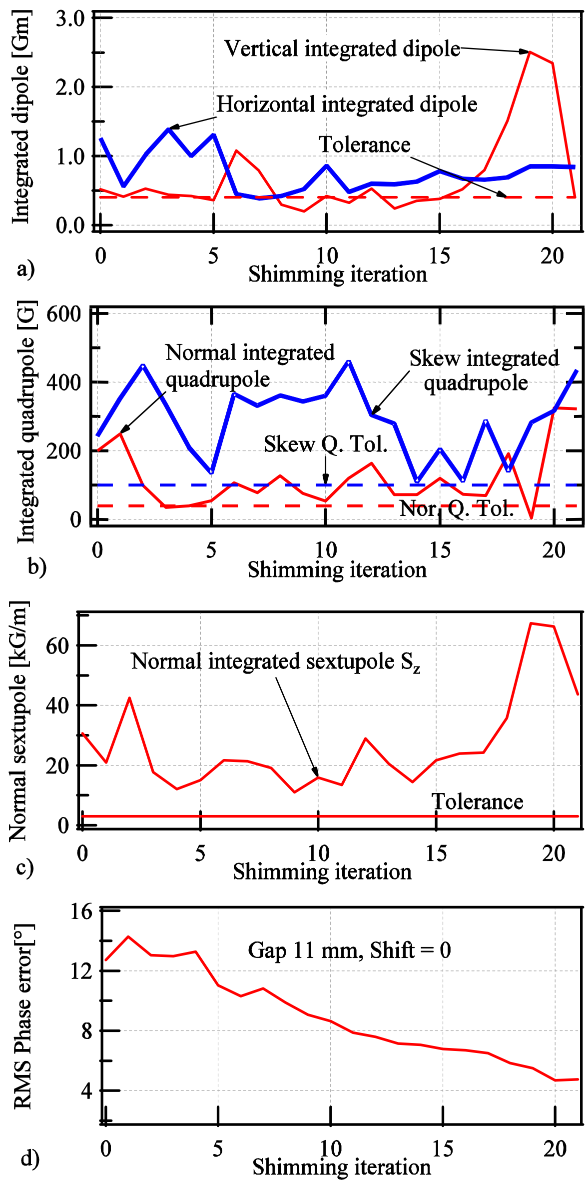

Figure 3: HU36 maximum variation with phase shift at the minimum gap of the main characteristics versus the shimming iteration: a) on axis integral variation, b) quadrupole variation, c) sextupole variation. The RMS phase error is computed from local field measurement performed at minimum gap and null phase shift, and displayed versus the shimming iteration.

The measured field integral errors and the RMS phase error at the iteration 0 are quite large. It corresponds to the measurement performed after having completed the HU36 assembly. The large RMS phase error arises from a parabolic variation of the peak field along the longitudinal axis. Correcting such distributed errors involves displacing a large amount of magnets. Thus more than 15 iterations were necessary to decrease the RMS phase error below 6°. In addition the process saturates after 16 iterations, the phase error and the field errors could not simultaneously be lowered. This situation was quite unusual since with the APPLE-II built earlier, less than 10 iterations were needed to decrease both the integrated field and the RMS phase to specified tolerance.

Field integral hysteresis

Besides integrated multipole component errors another kind of integrated field error has been observed, a field integral hysteresis with the shift between girders, i.e. the field integral at a given shift depends on the previous values of the shift. Such error has already been observed at the Advanced Light source [12]. It has been studied in terms of "Shift dependent skew quadrupole". It arises from the mechanical deformation of the magnet holder with the magnetic force. Fig. 4 represents the integral field hysteresis measured at a null shift. At SOLEIL it is believed that the magnet blocks with a longitudinal magnetization cause the observed hysteresis. According to a RADIA model a small rotation of about 0.2 mrad around the vertical axis, which corresponds to a longitudinal deformation of about 20 µm, is sufficient to create such field integral errors.

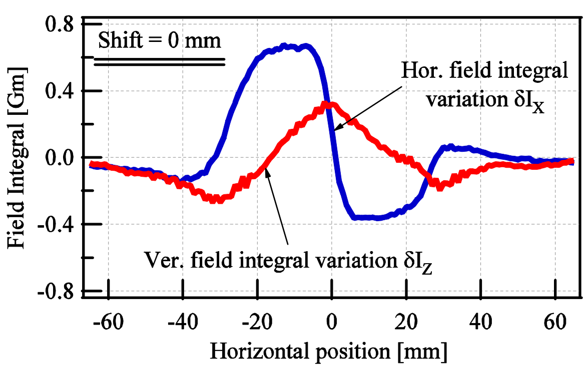

Figure 4: Field integral hysteresis at the null shift and the minimum gap. The hysteresis is the field integral difference measured at a null shift as the shift varies from –λ/2 and from λ/2 respectively.

Next steps

The undulator has been disassembled and new magnet holders made of stainless steel have been designed. The longitudinal deformation of the holders is expected to be smaller than 10 µm. The reassembling will start in June on another mechanical support which has mechanical deformation smaller than 50 µm.

CONCLUSION

At SOLEIL, 9 APPLE-II with period ranging from 80 mm down to 44 mm have been successfully assembled and corrected using a standard design. They operate without impacting the storage ring performances. For the HU36, due to a shorter period and larger fields, difficulties have been encountered during the correction. This work enabled to understand the limitation of our curent design in building short period high field APPLE-II type undulators, and to modify it accordingly. It is expected that the problem will be fixed with stronger magnet holders.

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