REVIEW OF INSERTION DEVICES DEDICATED TO HIGH ENERGY PHOTONS AT SOLEIL

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Abstract

Producing high energy photons between 1keV and 70 keV is a challenging topic in a medium energy storage ring. It requires up-to-date measurement techniques and specific Insertion Device (ID) technologies to produce high magnetic fields and short periods. At SOLEIL (2.75 GeV),six conventional in-vacuum hybrid undulators, operating at high radiation harmonics, and also one small gap multipole wiggler producing high magnetic fields were designed and built for hard X-ray beamlines. The construction has been progressively improved by choosing new magnetic materials of higher magnetization, developing additional correction techniques and bringing mechanical changes. A 2-m long full scale cryogenic undulator made of PrFeB and vanadium permendur has been built, measured, corrected and is to be tested soon on the beam. This paper presents the IDs dedicated for the high energy photons and their spectral performances.

INTRODUCTION

The production of high energy photons at SOLEIL is performed by the use of short period and small gap Insertion Device (ID). It allows producing high field and operating on high harmonics. Seven IDs are already installed on the storage ring to produce photons between 1 keV and 70 keV.

ID CHARACTERISTICS

All in-vacuum insertion devices (IVID) are hybrid type, composed of vanadium permendur poles and longitudinally (electron beam axis) magnetized magnets blocks. Presently, a first set of five in-vacuum undulators of U20 type(U20$^{(1)}$), one U24 and one in-vacuum wiggler WSV50 are installed in the storage ring (Table 1). One cryogenic undulator U18 has been built, measured and is installed. Two other U20, U20$^{(2)}$, made with new magnet grade (NdFeB), are under construction. The latterare. The spectral range is covered continuously by the WSV50 from 1 keV to 70 keV and by the in-vacuum undulators from 1 keV to 30-40 keV (Figure 1).The gap is controlled at the entrance and exit of the IVID by linear encoders (accuracy 1 µm). The carriage of WSV50 and also the next in-vacuum carriage (U20$^{(2)}$ and U18) are equipped with three motors (one for the vertical position of the carriage, two for the gap) instead of two.It allows the gap to be controlled at the entrance and also at the end avoiding taper effect and phase error increase. Taper was previously reduced by the use of a backlash of 250 µm during the magnetic measurements.

Table 1: IVID Characteristics. B_r magnetisation of the blocks, L length of the magnetic system, Per. period and T° operating temperature.U20$^{(1)}$ and U20$^{(2)}$ corresponds to first and second series of U20.

	U20$^{(1)}$	U24	U20$^{(2)}$	WSV50	U18
Grade	SmCo	NdFeB	NdFeB	NdFeB	PrFeB
B_r[T]	1.05	1.17	1.22	1.26	1.57
H_{cj}[kA/m]	1600	2280	1100	2230	2390
L[m]	2	2	2	2	2
Per.[mm]	20	24	20	50	18
Gap[mm]	5.5	8 (5.5)	5.5	5.5	5.5
Field[T]	0.97	0.82 (1.2)	1.08	2.1	1.15
Motor number	2	2	3	3	3
T°[K]	293	293	293	293	77
ID number	5	1	2	1	1

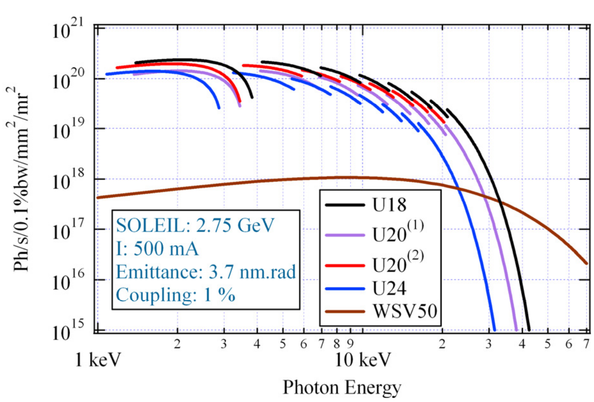

Figure 1: Spectral range covered by IVIDs of SOLEIL.

IVID ASSEMBLING AND CORRECTION

The magnetic system consists of two girders on which two types of holders are mounted. The holders are composed of either one Magnet only (M-holder) or two Poles and one Magnet (PMP holders).

The assembling is performed iteratively period by period with a home-made code,IDBuilder, whichis based on a genetic algorithm [1]. From the magnetic field integrals in both horizontal and vertical planes versus the horizontal position, the algorithm predicts the holders to be installed for the next period. IDBuilder is also used after assembling for the correction of multipolar terms, the spectral shimming and the trajectories straightness. It predicts the number, the horizontal and vertical position of magic fingers to be installed at each ends of the IVIDs and the vertical position of magnets and holders to reduce the phase error.Figure2 shows the evolution of the phase error of U20 n°5 and U24.

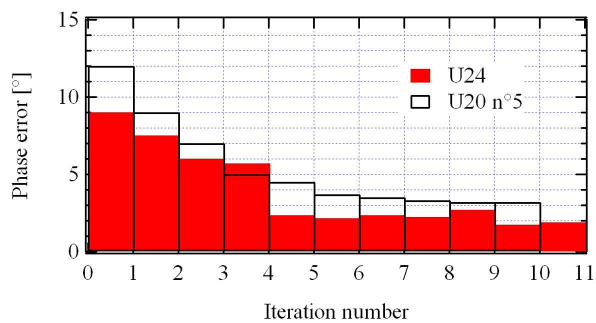

Figure 2: The phase error versus iteration number.

U20

At the first beginning of the IVID construction, the use of SmCo was preferred to NdFeB because of the risks of demagnetization due to irradiation [2,3] and the baking of the magnetic system.The first five hybrid in-vacuum undulators U20 have been in particular equipped with SmCo. Even more resistant to irradiation and heating SmCo offers a lower magnetisation thanNdFeB. The U20 deflection parameter K is limited to 1.8 which generates a spectral hole between the first and third harmonic. However, except for particular use at SOLEIL, most of the experiments using IVIDs require operation on high harmonics. A particular attention is paid on the phase error to avoid a strong reduction of the brightness. The phase error σ_ϕ of the five installed U20 is comprised between 2.6° and 3.2° at minimum gap which allows to operate routinely up to the 19th harmonic. The reduction factor of brightness to the phase error(ratio between the brightness of the real ID and the brightness of the designed ID) is plotted in figure 3.

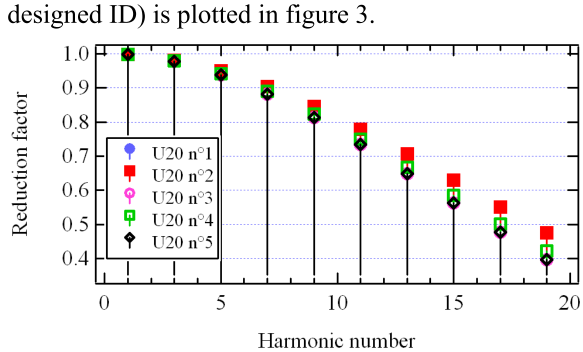

Figure 3: Reduction factor of brightness versus harmonic number.

Integrated multipoles are corrected by the use ofNdFeB magic fingers. In addition, special magic finger holders have been built to correct the dynamic field integral resulting from the small transverse size of the poles [4]. Even if the dynamic field integral of U20 (0.6 G.m maximum) is a weak, the cumulative effect of all IDs cannot be neglected on intermediate energy machine.

A second series of U20 (U20$^{(2)}$ in the table 1) has been designed to reduce the spectral hole between the first and third harmonic. The magnet blocks have been replaced by NdFeB magnets with higher magnetization. A gain of 11% of field has been reached. One of the two planned U20$^{(2)}$ has been already assembled and measured. Magnetic corrections of the ID are under progress.

U24

U24 is composed of 82 periods of 24 mm. Due to its position in the medium straight section (installed in a chicane andshifted by 1.52 m from the center), the gap of U24 is limited to 8 mm instead of 5.5 mm usually.The design of U24 differs from U20 only by the thickness of magnets and poles. As U20$^{(2)}$, U24 uses NdFeB magnets (B_r=1.17T). The magnetic field is 0.82T at the operating gap of 8 mm and the phase error is 1.9° (Figure 4).

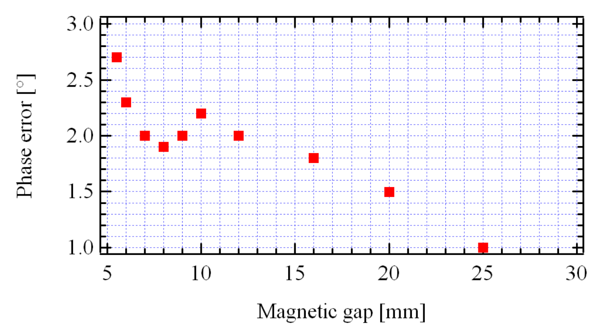

Figure 4: Phase error versus the magnetic gap.

The effect of the 250 μm backlash has been evaluated from the magnetic measurements (Figure 5) on the 17th harmonic at minimum gap (8 mm) using B2E [5]. When operating without the backlash, the phase error increases from 1.9° to 5.4° due to the appearance of a taper between the entrance and the exit of the IVID (20 μm). This effect has been already observed on U20s but with a lower magnitude (10 μm). The use of the backlash has reduced reproducibly the taper of U24 down to 5 μm.

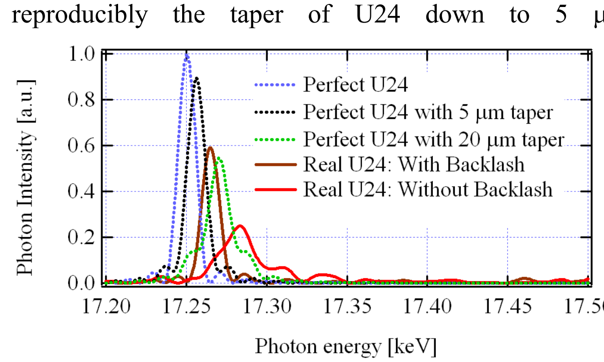

Figure 5: Effect of the backlash at 8 mm gap on the spectrum (17th harmonic) computed from the magnetic measurements (plain lines) and the effect of a taper between girders (dashed lines).

To avoid the any residual taper, the carriages of WSV50, U20(2) and U18 have been equipped with an additional motor.

WSV50

The in-vacuum wiggler WSV50, composed of 38 periods of 50 mm is also equipped with NdFeB magnets and vanadium permendur poles [6]. The small gap of 5.5 mm and the high magnetization of magnets (B_r=1.26T) permit to reach 2.1 T (Figure 6).

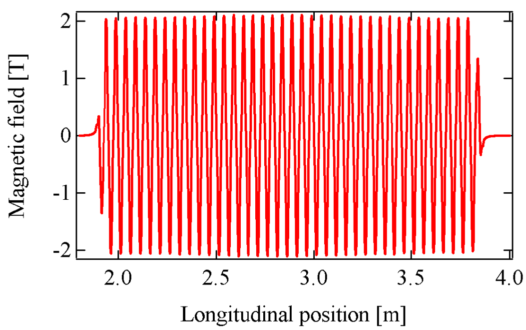

Figure 6: Measured field at minimum gap of 5.5 mm.

Each magnet girder is made of stainless steel and is supported by 2 pairs of rods installed on 2 brackets. The gap between jaws is checked along the wiggler axis via a magnetic ball target by an optical device. To overcome the high magnetic forces (8.5 tons) a compensation system has been designed and built at SOLEIL. It is composed of springs installed apart from the magnet arrays. The repulsive force of each spring is tuned by means of spacers which allows the magnet girders to be flattened and the peak field dispersion to be minimized. After correction of the girder deformation due to an excess of repulsive force at the wiggler extremities, the phase error drops from 19° to 4.2°. The relative peak dispersion decreases also from 1.22% to 0.36%. It results in an increase of the radiated flux.

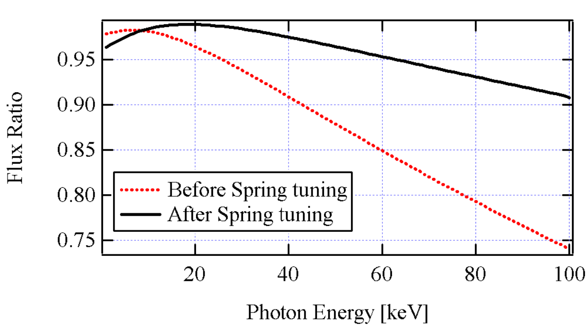

Figure 7: Reduction factor of the radiated flux.

The reduction factor of flux (ratio of the total flux of the real wiggler to the total flux of the designed wiggler) has been calculated with SRW code [7] and is plotted in figure 7.

U18

U18 has been constructed in the frame of a R&D research program in order to increase the peak field on IVIDs. It is composed of PrFeB magnet [8]. Even if this grade cannot be baked,the magnetisation and the coercivity are strongly increased when operating the magnets at LN_2 temperature. In addition the increase of the magnetization in not limited by the SRT effects [9] as with NdFeB which makes the temperature control easier (no heating). The cryogenic undulator design is derived from the actual design of U20(2). The magnetic field has been measured with a dedicated bench which is installed inside the vacuum chamber and removed after measurements. At 293K, the magnetic field is 0.9T at minimum gap of 5.5 mm and the phase error 2.8°. When cooling down to 77K, a gain of 10% is reached and the phase error of 9° has been reduced to 3.5°.

SUMMARY AND OVERVIEW

Eight IVIDs have been built at SOLEIL to cover the hard X-Rays region. The construction have been progressively improved by the change of magnetic material (switch from SmCo to NdFeB and toPrFeB) which allows both to cover the spectral hole between harmonics (U20(2)) and to reach higher photon energy (U18). The gap control with two motors and the tuning of the girders rods have improved the optical performances of the IVIDs (phase error). A small gap multipole wiggler has been constructed and installed. The control of the girder deformations by means of springs leads to the optimization of the photons flux in particular at high photon energy. A U18 cryogenic undulator has been designed, built and measured at SOLEIL and is in phase of installation. The operation of the PrFeB magnet at 77°K leads to a gain of 10 % of magnetic field. These encouraging results allow to plan future IVIDs operating at smaller gaps (~4.5 mm) and also using cryogenic magnets.

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