DEVELOPMENT AND INSTALLATION OF INSERTION DEVICES AT SOLEIL

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Abstract

SOLEIL storage ring presents a very high fraction of the total circumference dedicated to accommodate insertion devices. Over the planned 25 insertion devices (ID) presenting a large variety of systems, 17 have been already installed and commissioned in May 2009 (14 are now in place). The present status of the SOLEIL ID is given in particular with their achieved performances.

INTRODUCTION

SOLEIL being composed of a 2.75 GeV storage ring, a wide spectral range is covered via bending magnet radiations and a rich panoply of insertion devices [1] (see Table 1). The UV-VUV region is covered with electromagnetic (EM) devices (1 HU640 [2] and 3 HU256 [3]) [4], offering tuneable polarisations. An electromagnet/permanent magnet undulator using copper sheets as coils for fast switching of the helicity is under construction [5]. 13 APPLE-II type undulators, with period ranging from 80 down to 36 mm, provide photons in the 0.1-10 keV region, some of them featuring tapering or quasi-periodicity. In-vacuum undulators cover typically the 3-30 keV range whereas an in-vacuum wiggler (WSV) [6], with compensation of the magnetic forces via adequate springs is designed to cover the 10-50 keV spectral domain. R&D on cryogenic in-vacuum undulator has also been launched [7]. A magnetic chicane using permanent magnet dipoles has also been designed in order to accommodate two canted undulators (for 2 biology beamlines) in the same straight section. The brilliance of the different insertion devices of SOLEIL and the bending magnets (BM) is plotted in Figure 1.

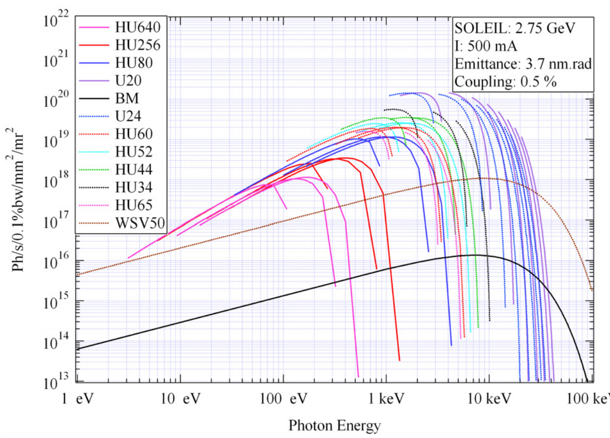

Figure 1: Average predicted brilliance of the SOLEIL insertion devices calculed using SRW [8].

Table 1 : Characteristics of the SOLEIL IDs. Technology (Techno), Undulator (Und.), Apple-II (A-II), In vacuum (SV), Circular (C), Linear Horizontal (LH), Linear Vertical (LV), Aperiodic Linear Vertical (LHA), Aperiodic Linear Vertical (LVA). Periodicity (Period) : Periodic (P), Aperiodic (A), Quasiperiodic (Q). Deflection parameter (K), Number of periods (N_{period}), Straight section (SS) : short (C) β_x= 17.8 m, η_x= 0.285 m, β_z= 1.75 m, medium (M) β_x= 4 m, η_x= 0.15 m, β_z= 1.77 m, long (L) β_x= 10.1 m, η_x= 0.2 m, β_z= 8 m.* value for SmCo magnets(1.05T for NdFeB).

	HU640	**HU256**	**HU80**	**HU65**	**HU64**	**HU60**	**HU52**	**WSV50**	**HU44**	**HU40**	**HU36**	**U24**	**U20**	**U20cryo**
Number	1	3	3	1	1	2	2	1	2	1	1	1	5	1
Energy (keV)	0.005-0.04	0.01-1	0.08-1.5	0.35-0.9	0.35-0.9	0.1-4	0.5-6	10-50	1-8	2-9	2-10	5-15	3-20	1-30
Type	Und.	Und.	Und.	Und.	Und.	Und.	Und.	Wiggler	Und.	Und.	Und.	Und.	Und.	Und.
Techno	EM	EM	A-II		A-II	A-II	A-II	SV	A-II	A-II	A-II	SV	SV	SV cryo
Polarisation	C, LH, LV var.	LH, LV, C, LHA, LVA	C, LH, LV	C, LV	C, LH, LV	C, LH, LV	C, LH, LV	LH	C, LH, LV	C, LH, LV	C, LH, LV	LH	LH	LH
Period	P	A	1Q-2P	P	Q	P	P	P	P	P	P	P	P	P
Kz Kx	5.4 6.6	7.9 10.6	5.7 6.4	1.46	3.7 5.2	3.1 4.5	2.6 3.7	9.9	1.7 2.6	1.4 2.2	1.8 2.5	1.88	1.79	2.35
$B_{x\,max}$(T) $B_{z\,max}$(T)	0.09 0.11	0.33 0.44	0.76 0.85	0.24 0.24	0.62 0.86	0.6 0.8	0.53 0.76	2.1	0.41 0.64	0.37 0.58	0.53 0.74	0.84	0.96*	1.25
N_{period}	14	12	19	25	25	26	30	38	36	40	44	81	98	98
SS	L	M	M	M	M	M	M	C	M	M	C	M	5 C, 1 L	

APPLE-II undulators are produced using NdFeB magnets with a remanent field B_r of 1.22 T, in-vacuum undulators have been initially built using SmCo magnets (B_r =1.05 T) and now evolve in employing NdFeB magnets (B_r =1.17-1.25 T).

The magnetic measurement laboratory is equipped with three benches composed of 3D Hall probes (BELL GH 701 with 1 G accuracy) and bodyless coils dedicated to the field integral measurements (with 3μTm accuracy). For EM undulators, dedicated benches were used (Hall probe, stretched wire for HU256, Hall probe and coil with interferometer for HU640). A pulse wire measurement technique is under test for the in vacuum wiggler and possibly the cryogenic undulator. After the modelisation performance with RADIA [9], the magnetic components (field, field integrals, quadrupolar and sextupolar components) and radiation properties (in particular the field errors) are optimised at different steps of the construction of the ID using the in-house code ID-Builder [10] based on a genetic algorithm. The residual field integral should not lead to a beam displacement larger than 10% of the beam size in the considered plane in the given straight section. Residual focusing should not exceed 10% of the natural focusing occuring in the plane of the magnetic field. The natural focusing is given by $G=2\pi^2 mcL_{und}K^2/e\lambda_u^2\gamma$, with, L_{und} the ID length, λ_u its period and γ the Lorentz factor. The resulting tune shift is then proportional to the mean betatron function at the undulator location in the given plane. Skew integrated quadrupole should not modify the total coupling by more than 10^{-4}.

After installation on the storage ring, the residual field integrals are measured in both planes using Closed Orbit Distortions (COD) and compared to the magnetic measurement results. Step by step feedforward (FFWD) tables are applied for the field integral compensation. In order to alleviate the residual COD spikes resulting from the bad synchronization between the main and correction fields, the on fly FFWD compensation was successfully tested for motorised IDs by using the gap encoders. An analog FFWD was also tested for the EM ID. Whereas the final version of the control of the ID is being worked out, it should be noticed that these spikes are significantly reduced thanks to the Fast Orbit Feedback [11]. Besides, FFWD is also planned to be implemented on the tune shifts induced by the ID, a feedback on the tunes being already operational [12]. Table 2 presents the measured field components for several SOLEIL undulators.

The commissioning of the radiation performed by the beamline scientists in close collaboration with the insertion device group is not reported here.

ELECTROMAGNETIC UNDULATORS

HU256 consists of alternated horizontal and vertical coils with iron poles [3].

HU640 is composed of pure racetrack coils arranged in adequate positions to produce all kinds of photon polarisation in the 5-40 eV spectral range. Coil 1 and Coil 2 produce the vertical field which are spatially shifted by $\lambda_u/4$ to allow a field longitudinal displacement between +/- $\lambda_u/2$. Coil 3 produces the horizontal field.

The HU256 and HU640 undulators are presently operated in defined hysteresis cycles, using defined transition cycles between the various polarisation modes. Such a hysteresis was not expected for HU640, which has been on purpose designed without iron poles. However it seems that its magnetic shielding is saturated by the conductors installed along the undulator. Because of the 10 m length and the precision of the magnetic measurements, such a phenomenon has not been put in evidence during the laboratory magnetic characterisation. We notice that the presence or not of magnetic shielding around the magnetic system affects significantly the hysteresis width. We plan to suppress it soon. Also the skew quadrupolar terms of the HU640 are larger than expected in the horizontal field mode. Such observation is presently under investigation. We suspect the iron quality of the supporting columns of the undulator, which are planned to be replaced by non magnetic ones.

Table 2: Residual field on-axis integrals Ix, Iz, quadrupolar Gx Gz and sextupolar Sz components measured with the electron beam (*or in the magnetic lab*) for maximum magnetic field and for the different configurations

		$I_x(x)$ G.cm	$I_z(x)$ G.cm	$G_x(x)$ G	$G_z(x)$ G	S_z G.cm^{-1}
HU256 Cassiopee	LH			+5	-73	-300
	LV			-33	-100	+120
	C			29	0	
HU256 Pléiades	LH			-23	15	
	C			53	10	
HU640	LH	10	10			
	LV	5	7	+260	+404	-306
HU80 Pléiades	LH			0	-175	-2390
Phase +40	LV			+210	0	0
Phase +20	C			+80	-200	0
HU52 Deimos	LH	-40 *-35*	-21 *-10*	-64	-35	+33
Phase +26	LV	-20 *-4*	17 *8*	-50	+61	+178
Phase +13	C	-20 *-13*	-15 *-15*	-24	+11	+136
U20 Swing	LH			+60	+120	+1230

APPLE-II TYPE UNDULATORS

Seven Apple-II ID are installed on SOLEIL. Permanent magnets were purchased from either Vacuumschmelze or Atlas Magnetics. A good agreement is obtained between the on-axis field integrals measured in the lab and the one deduced from the COD, without applying FFWD corrections, as shown in figure 2 and figure 3. Discrepancy may result from the misalignments (typically

100 µm or 100 µrad), the precision of magnetic measurements, and/or slight mechanical changes during transport from the magnetic hall to the ring.

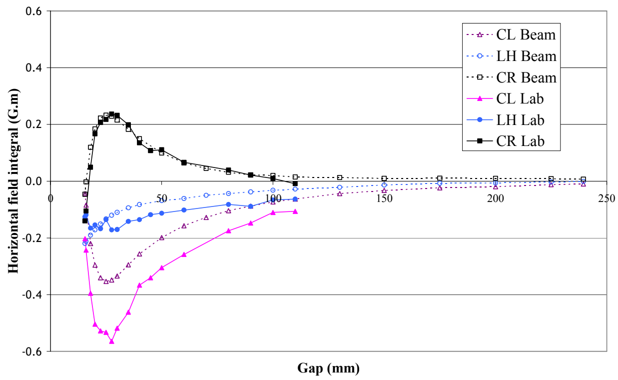

Figure 2: Comparison between the horizontal field integral from magnetic measurements and electron beam based measurements for HU52 LUCIA.

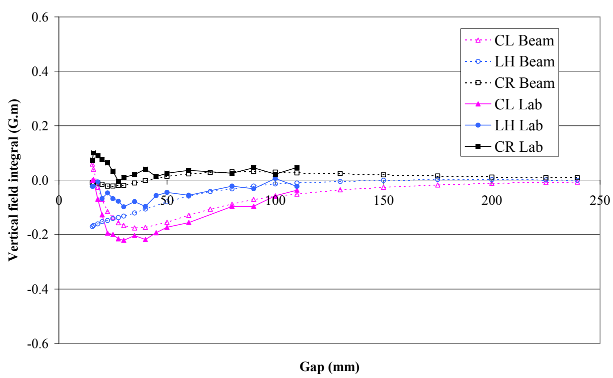

Figure 3: Comparison between the vertical field integral from magnetic measurements and electron beam based measurements for HU52 LUCIA.

IN VACUUM INSERTION DEVICES

Five U20 in-vacuum undulators are composed of sandwiches of vanadium poles and SmCo permanent magnets. U24, further U20 and WSV are using NdFeB magnets (from Neorem for U24 and Vacuumschmelze for WSV) for larger remanent fields. Some large sextupolar components have been measured and there are some differences in the induced chromaticities between the different in vaccum ID. Besides, the initial design of the RF transitions between the magnetic arrays and the adjacent vacuum chamber aiming at limiting the impedance growth due to the gap change led to some heating at very high current operation. It could be understood with the analysis of the wakefields and ANSYS calculations. A new taper design with a better thermal contact and still no water cooling was tested successfully and showed it was not heating anymore. However during the test, the NiCu liner of the ID was not enough strengthened and was unfortunately damaged by the beam.

To cover the 10-50 keV spectral range an in-vacuum hybrid wiggler was preferred to a superconducting wiggler despite a 30 % drop of the flux at 50 keV. To minimize the high magnetic forces acting on magnet arrays (10 Tons), a compensation mechanical system composed of springs have been developed and bench tested. The complete study (optical performance, magnetic design and frame) has been performed at SOLEIL. The Wiggler is presently under magnetic assembling.

R&D on cryogenic undulator (U18) is launched. Different magnet grades have been tested at various temperatures with a magnetometer for selecting the most suitable one and properly calculating the interaction for a magnet assembly. A model of 4 periods is presently under cryogenic and magnetic tests. The design of the mechanical, cryogenic and magnetic system with measurement system is under finalisation.

CONCLUSION

SOLEIL had started the ring commissioning with already a few ID in place in 2006. Since then, several ID have been built each year, and so far 16 ID have been commissioned. Two of them were removed from the ring (1 Apple-II for change of position and 2 in vacuum ID for liner and taper check). Two others (1 Apple-II and 1 U24) are ready for installation. The 3 presently installed in vacuum IDs have to be modified to change the RF tapers without affecting the user beamtime (typically the operation should be performed within a shutdown period) and the steel holders of the HU640 will be changed. In the future, the EMPHU, two other APPLE-II, the in-vacuum wiggler and one U20 will be built. R&D is progressing on the cryogenic undulator. When the first version of all the SOLEIL IDs will be finished, some upgrades are planned such as the change of the carriage of some APPLE-II for providing a 180° change of the polarisation, the remplacement of SmCo to NdFeB magnets for the in vacuum ID… New undulators or wigglers are also under discussion such as one for the slicing / tomography experiments, a second one for another tomography beamline.

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