SOLEIL INSERTION DEVICES: THE PROGRESS REPORT

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Abstract

The French national synchrotron radiation source SOLEIL is planned to start operation in 2006 with several different insertion devices installed in the storage ring either from "day one" or within the first year. The list of high-priority insertion devices (IDs) includes: 640 mm period fast-switching elliptical electromagnet undulator, offering advanced possibilities for fine-tuning of polarization states of the emitted radiation, three electromagnet elliptical undulators with 256 mm period, three 80 mm period APPLE-II type permanent-magnet undulators, and three 20 mm period planar hybrid in-vacuum undulators. The emission of all these undulators will cover wide spectral range extending from UV to hard X-rays. The conceptual design of all the IDs was done by SOLEIL; the final design and construction will be made by industrial companies and institutions with production capabilities. Before installation, all the IDs will be measured in the SOLEIL magnetic measurements lab. The paper describes peculiarities of the magnetic design, and the estimated optical performance of the SOLEIL undulators in various modes of operation.

INTRODUCTION

The synchrotron radiation source SOLEIL is a new third generation 2.75 GeV electron storage ring which is currently under construction in Saint-Aubin (near Paris) in France [1]. The facility will have a large number of various insertion devices which will serve for user beamlines specializing in scientific applications of UV, VUV, soft- and hard X-ray range radiation. According to the wish of the future SOLEIL users, all phase I insertion devices are undulators. The undulators dedicated for UV, VUV and soft X-rays are elliptical, with variable polarization state of the emitted radiation; for hard X-rays, planar in-vacuum undulators will be used. Table 1 lists the undulators required for the phase I. The names of the IDs include their period lengths in millimeters.

The magnetic design and optimisation of all the IDs was done using the computer codes Radia [2] and SRW [3]. The effects of the IDs on the electron beam were studied numerically using the particle tracking codes BETA and TRACY [4].

As for July 2004, all main orders for the construction of the phase I insertion devices have been placed. The delivery of the "turn-key" undulators, and parts of those undulators which will be assembled magnetically at SOLEIL, is expected in 2005.

Four magnetic measurement benches for insertion devices will be installed at SOLEIL, including two special benches for long electromagnet undulators, and two "ESRF-type" benches for permanent-magnet and hybrid IDs.

Table 1: SOLEIL Insertion Devices for the phase I.

ID	Type	Spectral Range	Polarization
HU640	EM (AC/DC)	5 eV - 40 eV	Elliptical
HU256	EM (DC)	10 eV - 300 eV	Elliptical
HU80	PM (APPLE-II)	50 eV - 2 keV	Elliptical
U20	PM (hybrid)	1.3 keV - 15 keV	Linear

ELECTROMAGNET UNDULATORS FOR UV AND VUV

Elliptical electromagnet undulators of two different types, with the periods of 640 mm and 256 mm, were designed at SOLEIL for UV/VUV spectral range [5].

HU640

HU640, the elliptical electromagnet undulator with 14 full periods a total length of ~10 m, is dedicated for the DESIRS (dichroism and high-resolution spectroscopy) beamline of SOLEIL. This beamline, transferred from the SUPER-ACO light source, will transport radiation using quasi-normal incident angles on mirrors. Because of this, reflection coefficients for the horizontal and vertical polarization components of the radiation, and the phase shift between the components, strongly depend on photon energy [6]. The design of the undulator allows for compensation of these effects. HU640 is composed of three sets of coils, without iron yokes. One set of coils produces horizontal magnetic field (H-coils); the other two sets produce vertical field (V- and SV- coils). The V- and SV-coils are shifted longitudinally with respect to each other by a quarter of period (see Fig. 1). Such configuration allows, via adequate balance of currents in the coils, to create arbitrary phase shift between vertical and horizontal magnetic fields, and to reach such elliptical polarization states of the emitted radiation, which are necessary for compensation of polarization distortions by the beamline optics.

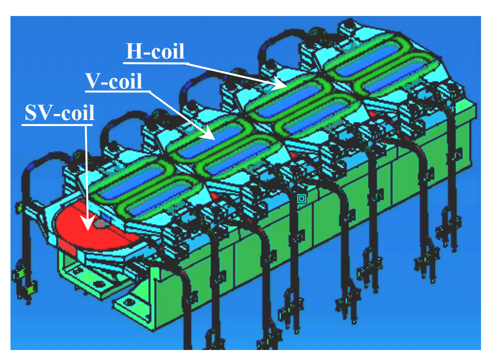

Figure 1: The undulator HU640 (lower part of the structure, 2 periods).

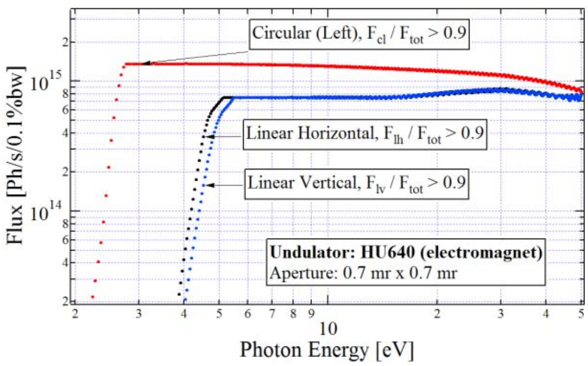

Figure 2: HU640 maximal spectral flux through finite aperture at circular left, linear horizontal and linear vertical polarization rates exceeding 0.9.

The coils are made of cooled copper hollow conductor (8.5 mm x 8.5 mm) and are driven by three bipolar power supplies: 590 A/90 V (H-coils), 430 A/120 V (V-coils) and 350 A/190 V (SV-coils). The peak field created by each of the three sets of coils independently is ~0.1 T. The helicity of the polarization can be switched at a frequency of 1 Hz, with a 200 ms rising time. The calculated maximal spectral flux, which can be emitted by this undulator at different polarizations, into a fixed aperture of 0.7 mr x 0.7 mr, is shown in Fig. 2.

The undulator HU640 will be fabricated for SOLEIL by DANFYSIK [7].

HU256

HU256 is an elliptical undulator with 12 full periods of 256 mm and total length of 3.6 m. The assembly consists of two sets of consecutive "closed" dipole magnets producing horizontal and vertical components of the magnetic field, with a phase shift equal to a quarter of period. The device imposes internal pumping of the vacuum chamber (NEG deposition), since no lateral access is available.

At a horizontal iron gap of 56 mm and a 250 A maximum current in a 24-turn coil (cooled hollow copper conductor of 5 mm x 5 mm cross-section), the optimized structure produces horizontal peak magnetic field of ~0.3 T. The vertical gap is 16 mm. At the maximum current of 180 A in the main coil of vertical dipoles (16 turns), the vertical peak magnetic field is ~0.43 T. 3D magnetostatics computation of the undulator HU256 is discussed in [8]. The calculated HU256 maximum-flux spectra at different polarizations are shown in Fig. 3.

The undulator allows for quasi-periodic operation [9]-[12], both for vertical and horizontal magnetic fields, in order to minimise linearly polarized emission at photon energies equal to multiples of the energy value of the fundamental, at which the photon flux is maximum. For this purpose, special power supplies and modulation coils are envisaged. The final optimization of the structure, and the manufacturing of three undulators HU256 will be done by Budker Institute of Nuclear Physics (Novosibirsk).

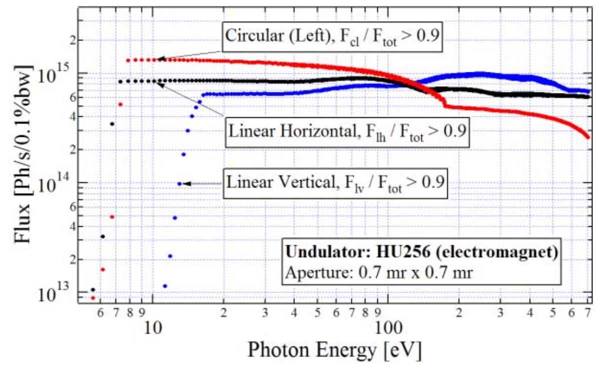

Figure 3: HU256 maximal spectral flux through finite aperture at different polarizations (for the polarization rates exceeding 0.9).

The undulators HU256 will be installed in medium-size straight sections of SOLEIL, for the beamlines CASSIOPEE (photo-electron spectroscopy), PLEIADES (polarized light source for electron and ion analysis from diluted excited species) and ANTARES (Spanish beamline at SOLEIL, dedicated for Fermi-surface mapping with spin analysis).

APPLE-II UNDULATORS FOR SOFT X-RAYS

To provide high flux of circularly polarized radiation in the soft X-ray spectral range, the construction of several APPLE-II undulators [13] is planned at SOLEIL. These undulators will operate out of vacuum, with minimal magnetic gap of ~15 mm.

The first three APPLE-II undulators have period of 80 mm. The construction of these undulators is currently in progress, subject of collaboration between SOLEIL and ELETTRA. In these undulators, NbFeB magnet blocks of square cross-section (28 mm x 28 mm) with the remanence of ~1.2 T, are used. The undulators contain 19 full periods for a total length of 1.6 m; the vertical magnetic field is symmetric in longitudinal direction. A quasi-periodic option will be realised (on the demand of users) by vertical displacement of certain magnets with longitudinal orientation of the magnetization axis [11].

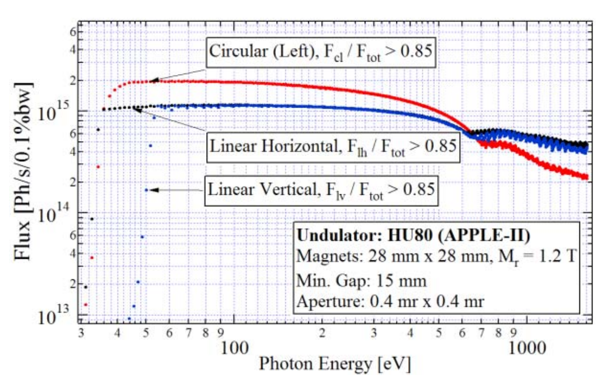

Figure 4: Maximal spectral flux through finite aperture at different polarizations, optimised vs vertical gap and longitudinal shift of magnet arrays of the undulator HU80 for each photon energy between 30 eV and 1.6 keV.

Figure 4 shows calculation results of the maximum spectral flux through finite aperture, which can be emitted by the undulator HU80 at circular left, linear horizontal and linear vertical polarizations. The optimisation for the flux was made versus vertical gap and longitudinal shift of the magnet arrays, based on the results of magnetostatic computation, at a given constraint on minimal acceptable polarization rates.

The first three undulators HU80 will be installed in medium-size straight sections of SOLEIL, for the soft X-ray beamlines TEMPO (time-resolved photo-electron spectroscopy), MICROFOC (micro-focus beamline for imaging and resonant scattering in magnetic systems), and PLEIADES. The undulator of the TEMPO beamline is considered for the use as a soft X-ray radiator in the SOLEIL femtosecond slicing experiment [14].

IN-VACUUM UNDULATORS FOR HARD X-RAYS

Producing a high flux of hard X-ray emission into a small angle (in the range of sub-mrad) in an electron storage ring with the energy of 2-3 GeV, requires small-period undulators capable of producing relatively high peak magnetic fields (>1 T). Pure permanent-magnet or hybrid undulators, operating at very small magnetic gap (~5 mm), i.e. inside vacuum, partially satisfy these requirements [15]. The technology of these insertion devices is currently in mature state, and "turn-key" solutions from different suppliers are available [7], [16].

The undulator period of 20 mm was chosen for three SOLEIL beamlines: PROXIMA-1, CRISTAL and SWING, specializing respectively in protein crystallography, condensed matter crystallography, and small-angle X-ray scattering. The type of the undulator structure is hybrid, with permanent magnets made of Sm_2Co_{17} and poles made of vanadium permendur. The length of the undulator is 2 m.

The calculated maximal spectral flux, which can be emitted by this undulator by adjusting gap for each photon energy, is shown in Fig.5. The calculation takes into account contributions of both odd and even harmonics of the undulator radiation.

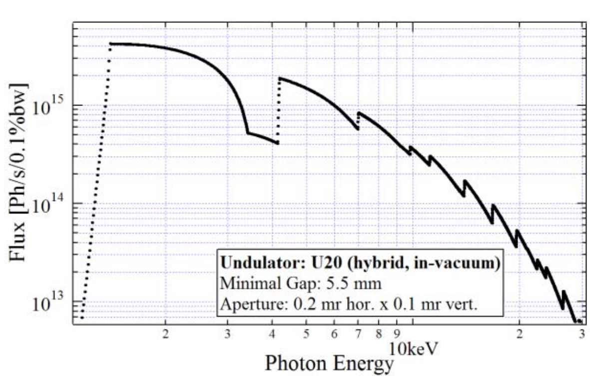

Figure 5: Maximal spectral flux through finite aperture which can be produced by the undulator U20.

A "turn-key" construction of the first in-vacuum undulator U20 for SOLEIL will be done by DANFYSIK. The magnetic assembly, measurements, and vacuum conditioning of the other two in-vacuum undulators U20 are planned to be done at SOLEIL, by the ID and Vacuum groups.

All in-vacuum undulators will be installed in short straight sections of the storage ring, which allow for small vertical gap and can accommodate only one undulator segment. One of the first in-vacuum undulators is planned to be used as hard X-ray radiator in the femtosecond slicing experiment [14].

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