RECENT DEVELOPMENTS OF INSERTION DEVICES AT THE ESRF

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Abstract

After 4 years of user operation, the ESRF is operating 44 segments of Insertion Devices serving 25 beamlines. Recent developments in the technology of Insertion Devices are discussed such as the design of passive phasing sections for both the pure permanent magnet and hybrid type undulator. A novel design of a short period variable polarization helical undulator is presented. It is made of both permanent magnets and coils. It will cover the photon energy range from 1 to 15 keV with a flipping time of a few milliseconds between left and right circular polarization. Finally, some perturbations induced by ambient residual field on hybrid insertion devices are reported.

1 STATUS OF INSTALLATION

The European Synchrotron Radiation Facility (ESRF) is a third generation synchrotron source optimized to produce hard X-rays in the 1 to 100 keV range. The majority of the beamlines use an insertion device (ID) as a source point which generates high fluxes and brilliance. The source is routinely operated with a stored current of 200 mA, an horizontal emittance of 4 nm and a coupling smaller than 1% resulting in a record brilliance reaching 10^{20} phot./sec/.1%/mm2/mrad2 around 5 keV. The Facility has been in user operation for more than 4 years and the number of IDs has gradually increased to reach 44 segments serving 25 beamlines (Table 1). All IDs except the 4T superconducting wiggler are made of permanent magnets with magnet blocks in the air on both sides of the vacuum chamber. Each segment is 1.6 meters long and three segments can be installed on a single straight section. 15 (9) beamlines operate with a minimum magnetic gap of 16 mm (20 mm). A prototype undulator chamber with 10 mm external aperture has been successfully tested which does not degrade the vacuum of the ring and therefore the lifetime of the stored beam (> 50 hours at 200 mA). These new chambers will gradually replace the existing ones. All permanent magnet IDs have been mechanically and magnetically designed and field measured at ESRF.

A special multipole and spectrum shimming [1] has been developed and systematically applied. Multipole shimming eliminates the need of dipole or multipole correction on all conventional undulators. The spectrum shimming reduces the phase error from one period to the next allowing nearly ideal spectral performance of each segment on harmonics # 1 to 15.

ID #	Type	Period [mm]	Field [T]	Techno.
1	Wiggler	70	0.85	hybrid
	Undulator	42	0.56	ppm
2	Undulator	46	0.48	ppm
	Undulator	26	0.16	ppm
3	Undulator	42	0.56	ppm
	Undulator	42	0.56	ppm
6	Undulator	46	0.48	ppm
9	Wiggler	70	0.85	hybrid
	Undulator	46	0.62	ppm
	Undulator	26	0.27	ppm
10	Undulator	46	0.48	ppm
	Undulator	26	0.71	ppm
11	Wiggler	125	1.20	hybrid
	Undulator	34	0.70	ppm
12A	Helic. Und.	85	0.51	ppm
12B	Helic. Und	52	0.36	ppm
13	Undulator	46	0.65	hybrid
14	Undulator	42	0.56	ppm
	Undulator	23	0.20	hybrid
15A	Asym. Wigg	220	1.8	hybrid
15B	SuperCond.	200	4	superc.
16	Undulator	42	0.56	ppm
	Undulator	42	0.56	ppm
	Helic. Und.	52	0.36	ppm
17	Wiggler	150	1.9	hybrid
18	Undulator	23	0.21	ppm
	Undulator	34	0.42	ppm
19	Wiggler	150	1.9	hybrid
20	Asym. Wigg	210	1	ppm
	Undulator	48	0.5	hybrid
21	Wiggler	80	0.81	hybrid
	Wiggler	80	0.81	hybrid
22	Undulator	42	0.56	ppm
23	Undulator	48	0.65	ppm
	Undulator	46	0.62	ppm
	Undulator	44	0.59	ppm
24	Undulator	42	0.56	ppm
26	Undulator	42	0.56	ppm
	Undulator	42	0.56	ppm
30	Undulator	40	0.52	ppm
	Undulator	40	0.52	ppm
	Wiggler	70	0.82	hybrid
32	Undulator	48	0.50	ppm
	Undulator	40	0.40	ppm

Table 1: Type, spatial period, peak field and technology used to build the 44 IDs presently in operation.

The spectrum shimming has routinely been applied over the last three years to all undulators. Figure 1 presents the rms phase error at a 16 mm gap as well as the maximum rms phase error for any useful gap on the last 13 ndulators produced.

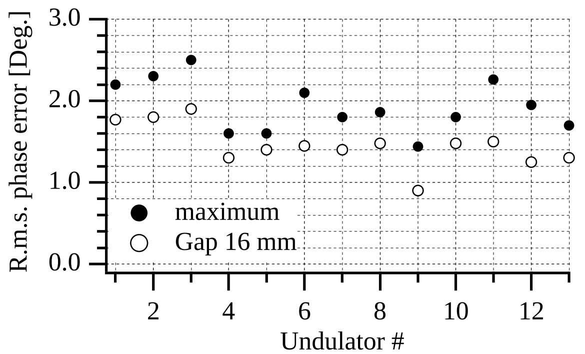

Figure1: rms phase error of the last 13 Undulators produced at ESRF.

2 UNDULATOR PHASING

2.1 Generalities

The motivation for the phasing between the undulator sections is to ensure that a three segment assembly produces the same spectrum as a 5m long single piece ID. The magnet termination should be carefully designed to minimze the field integral induced as one varies the gap of one segment while maintaining the other unchanged. The proper operation of such a termination allows the user to vary the length of its undulator by switching between one, two or three segments at any time, therefore optimizing the heatload conditions in the beamline to the ring current and photon energy.

2.2 Pure Permanent Magnet Assemblies

The first attempt to phase the undulator segments was tested on a pure permanent magnet assembly in 1995 [2]. It is now in use on 4 beamlines each operating two undulator segments of identical periods.

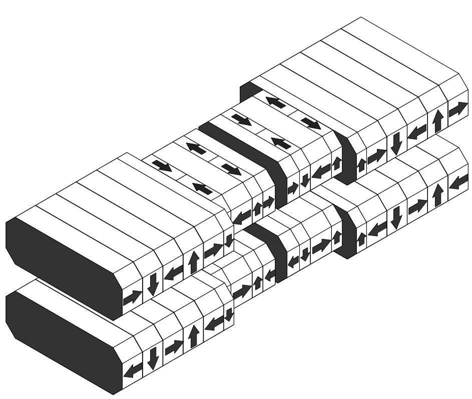

Figure 2: Phasing section for Pure Permanent Magnet. The distance between the magnet array is 6 mm (3 mm) for a period of 42 mm (20 mm).

The magnetic assembly is presented in Figure 2. The measured field integral produced at the junction between the segments is smaller than 30 Gcm for any gap combination of the segments (as low as 15 mm). These phasing sections are robust and inexpensive. They also allow the proper phasing of undulators of slightly different field or periods. As a result, almost all undulators produced at ESRF over the last two years are equipped with phasing sections.

2.3 Hybrid Assemblies

Recently, an attempt was made to phase three long period undulators for the ID21 microscopy beamline. The requirements were the operation of a single segment in the undulator regime at small gap and large field in order to lower the energy of the fundamental around 0.28 keV and to operate the three segments simultaneously above 2 keV. The large field and long period required for the low energy operation resulted in selecting the hybrid technology for the magnet assembly with a period of 80 mm. The difficulty met at the design phase in maintaining both the phase variation and the field integrals independent of the magnetic gaps was significant because of the large susceptibility of the iron poles. It required a large number of 3D magnetic field simulations performed with the code Radia[3]. The configuration retained is presented in Figure 3.

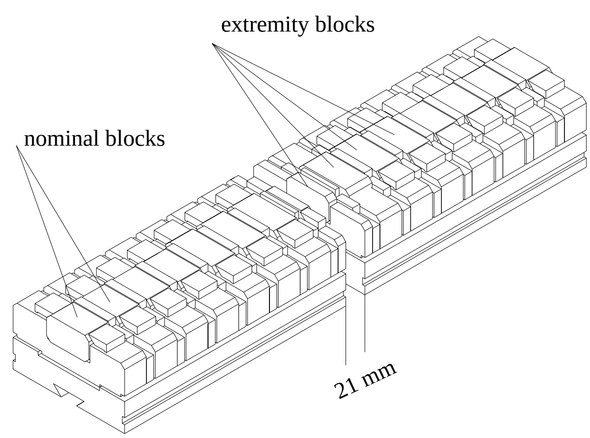

Figure3: Phasing section for an Hybrid Undulator. Due to the large interaction between magnet arrays, the distance between the arrays is increased to 21 mm resulting in some variations of the phase as a function of the magnetic gap.

The last magnet blocks have slightly larger dimensions than those in the middle of the undulator. To limit the differential field integral variation vs. gap to 125 G-cm, a large air gap of 21 mm between the segments has been selected. Due to this large distance between segments, the phase between the segments varies between 0 and 20 degrees in the useful gap range (35 to 100 mm) where phasing is required. This is sufficient to ensure the constructive interference for harmonic 1 but some degradation of brilliance takes place on harmonics 3 and 5 depending on the magnetic gap. To conclude, three phased undulator segments have been built with the hybrid technology, the effort required was much greater than for phasing pure permanent magnet devices and the performances achieved significantly poorer.

3 FAST SWITCHING HELICAL UNDULATOR

Producing circularly polarized radiation from insertion devices has always been a major priority at ESRF. The hard X-ray range (between 20 and 500 keV) is covered by three asymmetric wigglers installed on ID15A, ID15B and ID20 while the low energy (0.5 to 10 keV) is covered by three variable polarization helical undulators installed on ID12A, ID12B and ID16 which are among the beamlines the most demanded by the user community. These undulators are unique in the world. They produce an ellipsoidal magnetic field with an independent control by the user of the amplitude and phase of the vertical and horizontal magnetic fields [4].

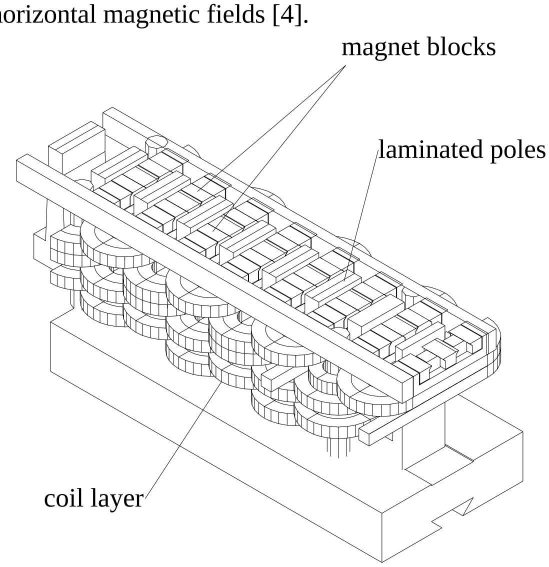

Figure 4: Design of the central part and termination of a novel type permanent -magnet / electro-magnet variable polarisation helical undulator.

During the three years of user operation, the most frequently performed field adjustment concerns the phase inversion which results in a flipping of the circular polarization between left and right. Such a flip takes a few seconds which is incompatible with the detection of a dichroism signal as low as 10^{-4}. To overcome this limit, a new variable polarization helical undulator presented in Figure 4 is being built. The vertical magnetic field is produced by a coil and laminated iron structure while the horizontal magnetic field is produced by an array of Sm_2Co_{17} permanent magnets located between the poles. Its period is 80 mm and its horizontal and vertical peak field is 0.21 T resulting in a deflection parameter K of 2.2. It covers the 1 to 15 keV range using harmonics 1 to 5. The horizontal (vertical) fields are tuned by changing the magnetic gap (coil current). The fast flipping of the polarization is achieved by inverting the current in the coil. A special power supply is being built which produces square shaped current between 300 and -300 Amp with a flipping time of a few milliseconds at a repetition rate from dc to 10 Hz. The magnetic field and field integrals in the central part and termination have been simulated and optimized using Radia.

4 AMBIENT FIELDS

The residual field observed in the ring tunnel can have significant consequences on the radiation and operation of the IDs. This field comes from the earth, ion pump and power cables of the dipoles, quadrupoles... It has been observed on ID16 that a 0.5 G horizontal component of field can bend the trajectory and reduce the undulator brilliance of a two segment device by 10% around 30 keV. Moreover for hybrid devices, this residual field magnetizes the iron poles resulting in a field integral on the electron beam which depends on the magnetic gap. For the same field of 0.5 G, we have observed (and confirmed with Radia) field integral variations larger than 100 Gcm over a 1.6 m segment when the magnetic gap is changed between 16 and 200 mm. This corresponds to an unacceptable displacement of the closed orbit by half the beam size in the vertical plane (on average). Proper measures have been taken to minimize this residual field , but because of this, active electro-magnet correctors are nevertheless required on a large number of hybrid devices.

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