RECENT ACHIEVEMENTS AND FUTURE PROSPECT OF ID ACTIVITIES AT THE ESRF

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Abstract

The latest developments concerning Insertion Devices at the ESRF are presented. These concern the operation of a 5m long undulator at a gap of 11 mm providing a brilliance close to 5 10^{20} phot/sec/.1%/mm^2/mr^2. A 1.6-m long in-vacuum undulator is operated at a 5-mm gap. Four 2-m long in-vacuum undulators are currently being manufactured. Three Apple II undulators are undergoing field measurements. The computation of the reduction of dynamic aperture induced by the Apple II undulator is presented together with its correction by a new type of shimming. A second quasi-periodic undulator has been installed, its spectral characteristics are close to expectations.

1 INTRODUCTION

The European Synchrotron Radiation Facility is now equipped with more than 60 segments of Insertion Devices (Ids) each 1.6 m long. With the reduction of the vertical emittance to 10 pm-rad [1], and the successful operation of a high heatload beamline front-end, a brilliance close to 5 10^{20} phot/sec/.1%/mm^2/mr^2 has been reached using a 5 m long 34 mm period undulator at a minimum gap of 11 mm (See Fig. 1).

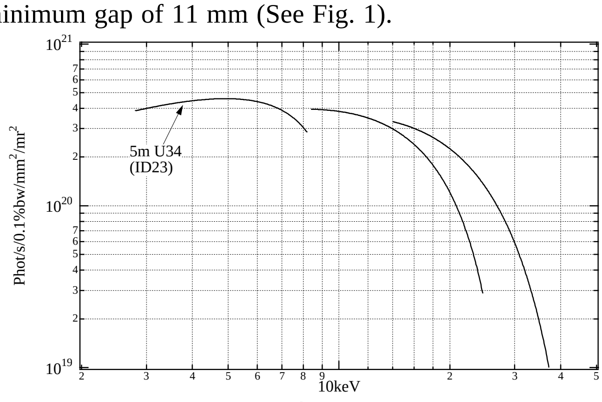

Fig.1: Ultimate brilliance reached with a 5 m long U34 and the low emittance lattice.

This paper reviews the latest developments of Ids namely, In-vacuum undulators, Apple II undulators and Quasi-periodic undulators.

2 IN-VACUUM UNDULATORS

2.1 Results with the prototype

The first operation of the ESRF prototype in-vacuum undulator was reported in [2]. The 23 mm period 1.6 m long hybrid undulator is now in routine user operation with a minimum magnetic gap of 5 mm. Fig.2 presents the measured lifetime as a function of the magnetic gap in 2 x 1/3 filling (200 mA) and 16 bunch (80 mA) modes. Thanks to a large pumping, no measurable Bremsstrahlung has been observed on the beamline for a gap as low as 4.5 mm.

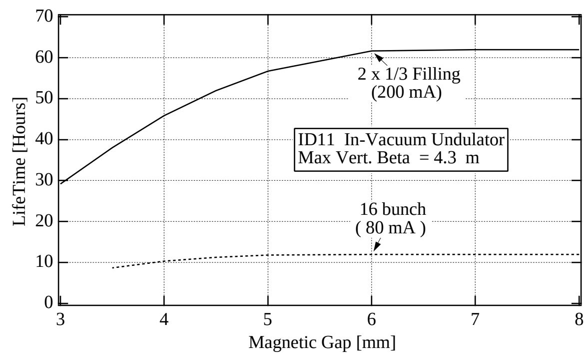

Fig.2: Lifetime as a function of the magnetic gap of the ID11 in-vacuum undulator

2.2 Future

A series of 4 in-vacuum undulators is presently being manufactured. They are all designed for an operation gap of 6 mm making use of Sm_2Co_{17} magnets which are more stable than NdFeB to any exposure (accidental or continuous scraping) to the electron beam and can be baked to higher temperatures [3] . Their length is 2 m and the periods are 17,18,21 and 23 mm. These undulators outperform existing 16-mm gap devices at energies above 20 keV. For a fixed energy of 12 keV (protein crystallography), they produce three times more flux than a 16 mm gap device of the same length.

3 APPLE-II UNDULATORS

Three 1.6 m long undulator segments of Apple II type are under construction. They have a period of 88 mm (HU88) and 38 mm (HU38) and are designed to operate with a minimum gap of 16 mm.

2.1 Effect on the beam

As one varies the phase Φ in an Apple II undulator (in order to change the polarization), one expects to observe three classes of perturbations to the beam: closed orbit distortion (cod), tune shifts (and associated betatron beat) and a possible reduction of the dynamic aperture resulting in shorter lifetime and injection problems. The cod is induced by the field and positioning errors of the magnets and by the extremities. A proper shimming and alignment as well as a suitable design of the extremities [2] ensure a negligible cod. In the absence of field errors, the horizontal (vertical) angular kick θ_x (θ_z) experienced by an electron in an undulator can be derived from [4]:

$$\frac{d\theta_{x,z}}{ds} \cong -0.57\ 10^{-3}\ \left(\frac{\lambda_0}{E}\right)^2 \frac{\partial\left(\hat{B}_x^2 + \hat{B}_z^2\right)}{\partial x, z} \qquad (1)$$

Where E the electron energy in GeV, λ_0 is the period in meter and $\hat{B}_x$ ($\hat{B}_z$) is the horizontal (vertical) peak field in Tesla and x and z are the transverse coordinates while s is the longitudinal coordinate along the undulator axis. The focusing and higher order terms are derived by further derivating $\left(\hat{B}_x^2 + \hat{B}_z^2\right)$ with respect to the transverse coordinates x and z. Fig.3 presents the horizontal and vertical peak field as a function of the horizontal position for a 3.2 m long HU88 at a gap of 16 mm and $\Phi = \pi/2$. The narrow profile of the horizontal field around the undulator axis results in a large second derivative $\frac{\partial \hat{B}_x^2}{\partial x^2}$ which is responsible for an important horizontal tune shift which varies very rapidly as a function of the horizontal position x (Fig.3). The electron energy is 6 GeV and the horizontal (vertical) beta functions are 35 (2.5) m.

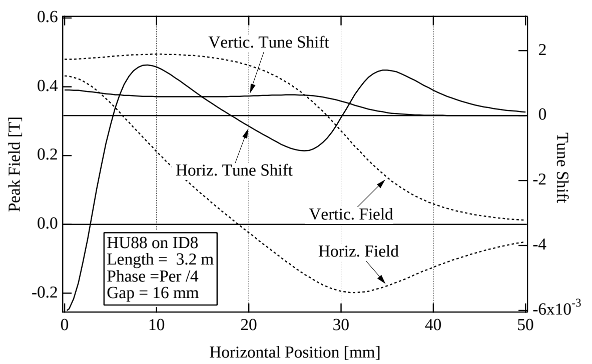

Fig.3: Horizontal and vertical peak field and tune shift as a function of the horizontal position in the mid-plane of the undulator.

The magnetic design (magnet height) has been optimized in order to minimize the variations of the energy of the fundamental (which depends on $\hat{B}_x^2 + \hat{B}_z^2$) with Φ. As a result of the various symmetries in the field, the sum of the on-axis vertical and horizontal focusing is almost independent of Φ[4]. Consequently, the tune shifts and the associated "beta beat" can be compensated by means of a pure quadrupole, the current of which is proportional to $\sin(\Phi)$. However, such a quadrupole will not correct for the variation of focusing vs. x. For a more detailed analysis of the problem, a recent version of BETA[5] was used in which the tracking of electrons in a real undulator field is implemented by means of Eq.(1). The fields $\hat{B}_x^2 + \hat{B}_z^2$ as a function of (x, z) are derived from a 3D field simulation in RADIA[6]. Fig.4 presents the dynamic aperture of the ESRF ring in the presence of a 3.2 m long HU88. Due to the E^2 scaling, the dynamic aperture is dramatically reduced at 3 and 1.5 GeV while it is essentially undisturbed at 6 GeV. The result is essentially the same whether the on-axis tunes are globally (family of quadrupoles) or locally (single quadrupole) compensated.

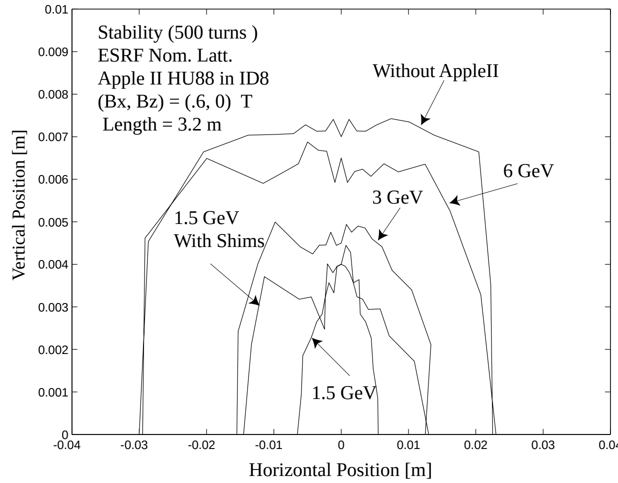

Fig.4: On-momentum dynamic aperture reduction induced by the HU88 at different electron energy. The phase is π and the gap is 16 mm.

Fig.5 presents the dynamic aperture at 1.5 GeV for three different settings of the phase: $\Phi = 0$ (Vertical field), $\Phi = \pm\ \pi/2$ (Almost circular field) and $\Phi = \pm\pi$ (Horizontal field). As expected, the dynamic aperture is restored when the field is purely vertical (conventional undulator) because the variations of tune shifts with x are strongly reduced.

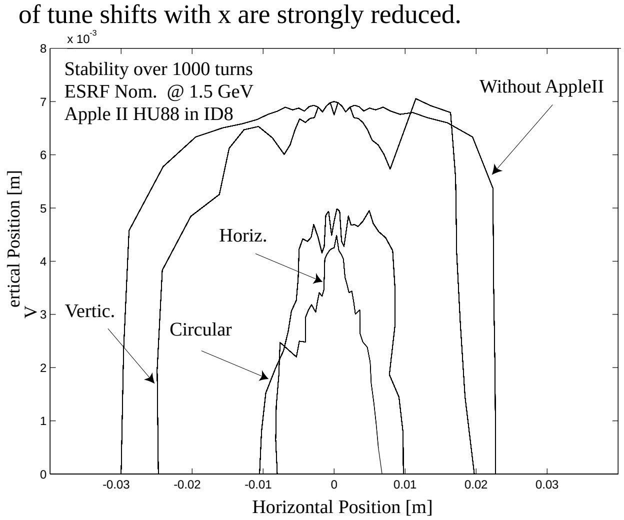

Fig.5: On-momentum dynamic aperture reduction induced by the HU88 for several polarizations.

A shimming has been studied to re-enlarge the dynamic aperture with the addition of a (first order in E) multipole field component in a manner somewhat similar to the proposed solution for a SPEAR Wiggler [7]. The shim geometry is shown in Fig.6. Such shims are placed on each of the four magnet arrays. They are designed based on the criteria of correcting the tune shift vs. x. The shim effect on the dynamic aperture is shown in Fig.4. The dimensions of the shims have been optimized to correct the on-axis tune shift vs. phase and gap, thereby eliminating any beta beat vs Φ. The field integrals induced by the shim have been computed with RADIA and checked on the measuring bench. The optimization was done rather quickly on a particular tune of the lattice, and it is believed that a deeper study of the question could result in an improved correction. These shims eliminate the need for any quadrupole driven correction. This type of shimming has a number of difference with conventional "multipole shimming". It consists in correcting second order (in the electron energy) effects with (first order) real multipoles. As a result, it is always made for a particular electron energy and it can, in most situations, never correct the whole second order effect.

The HU38 undulator has a lower field and is shorter, it does not need correction.

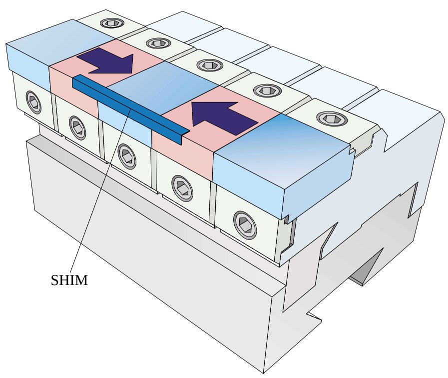

Fig.6: Shim geometry for both on-axis tune shift and dynamic aperture correction.

2.2 Field Measurements

The mechanical assembly of the magnets is shown in Fig.7.

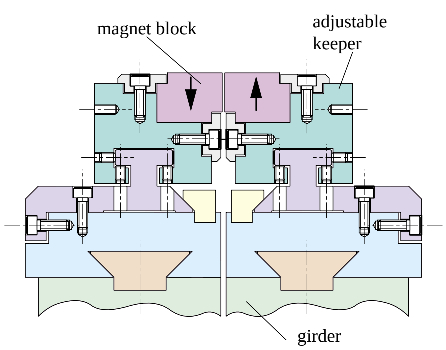

Fig.7: Mechanical set-up for the magnet assembly

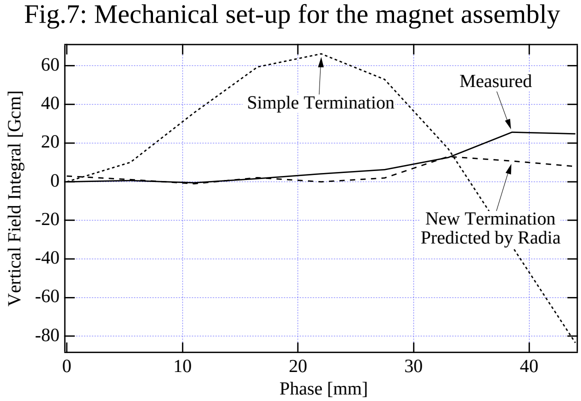

Fig.8 Vertical field integral measured on-axis of the undulator at a gap of 16 mm as a function of the phase.

The magnetic shimming is replaced with a mechanical shimming using screws and vertical positioning of the magnets. The field measurement and shimming of the HU88 undulator is presently under way. Fig.8 presents the vertical field integral measured on-axis of the undulator at a gap of 16 mm as a function of the phase. The field integral variations are smaller than 6 Gcm for any phase between $-\pi/2$ and $\pi/2$. The measured values are close to those predicted by RADIA for this special termination [8].

3 QUASI-PERIODIC UNDULATORS

Following the preliminary test of a new type of quasi-periodic undulator on ID6 [9], a 1.6-m long segment has been built and installed on ID27. It has a period of 54 mm and is similar to the prototype. The quasi-periodicity is obtained by displacing vertically certain magnets with horizontal magnetization by 5 mm. Fig. 9 presents the measured spectral flux in the 3-20 keV range which is in good agreement with the expected one. The discrepancies at low and large photon energies are due to the detector system.

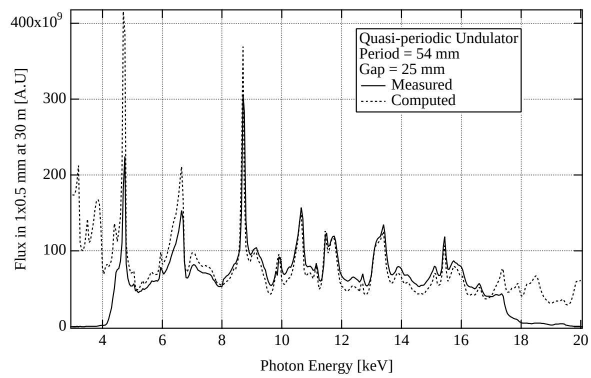

Fig.9: Measured and Computed spectrum from the quasi-periodic undulator installed on ID27.

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