DEVELOPMENT OF QUASIPERIODIC UNDULATORS AT THE ESRF

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Abstract

A prototype 1.6 m long quasi-periodic undulator has been built and tested on the ID6 Machine Diagnostic beamline of the ESRF. The magnetic design is very simple and compact giving a higher angular flux vs. undulator length compared to existing quasi-periodic magnetic designs. It has been placed together with a conventional 46 mm period undulator on a revolving structure which allows a quick comparison of the spectra produced by each device with the same condition of electron beam and beamline instrumentation. Around the gap of 29 mm, a suppression ratio of 8.3 and 11.3 on harmonics 3 and 5 have been observed.

1 INTRODUCTION

Conventional undulators have a periodic magnetic structure. As a result the spectrum of their radiation is made of a series of peaks harmonically related in which the energy of the third and fifth harmonics occurs at a frequency precisely equal to three and five times that of the fundamental peak. When tuned to wavelength λ, most grating and crystal monochromators have nonzero transmission at the wavelengths 3λ and 5λ. The transmission depends on the grating profile or Miller indices of the crystal being used. As a result of the undulator spectrum and imperfection of the monochromators, the so-called monochromatic beam is always contaminated, to some extent, by the harmonics. This problem can be eliminated by using a quasi-periodic undulator[1],[2]. In this paper, we review the results obtained on a compact new magnetic design of a quasi-periodic undulator and provide an experimental comparison of the spectral characteristics from this newly built device with a conventional undulator of the same length and period.

2 MAGNETIC FIELD

2.1 Magnetic Design

Figure 1 presents a 3D view of our magnetic design. It is easily derived from the conventional pure permanent magnet undulator by vertically translating a few H-magnets (blocks magnetized horizontally) by a value δ.

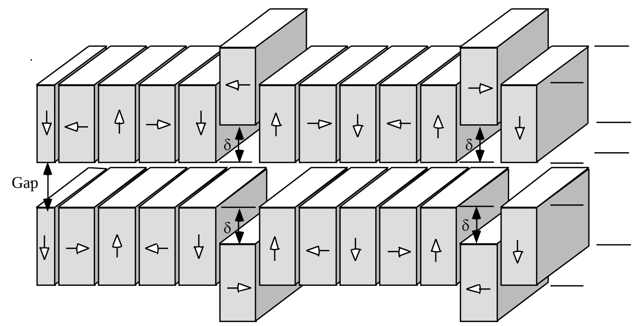

Figure 1: 3D view of the quasi-periodic undulator

The choice of the H-magnets to be displaced vertically is made as follows. All H-magnets of a single girder (upper or lower) are numbered from n = 1 to p. The following Fibionacci sequence of x_n is computed for each index n of H-magnet:

$$x_n = n + (1 / \eta -1) \left[\, n / (\eta +1) +1 \,\right] \qquad (1)$$

in which the bracket [y] denotes the greatest integer less than 1 and η is a dimensionless number also called the inter-lattice ratio. One easily shows that the sequence of x_n is such that $x_n - x_{n-1}$ is either equal to 1 or $1/\eta$. If it is equal to 1 the n-th H-magnet is untouched, if it is equal to $1/\eta$, it is vertically displaced by δ as shown in Figure 1. The other girder is processed symmetrically with respect to the median horizontal plane. By doing so, the electric field pulse vs. time emitted by a single electron in such an undulator presents two interlaced periodicities with period 1 and $1/\eta$. This magnetic design presents a number of advantages over existing designs of quasi-periodic undulators[2],[3]. It is much more compact longitudinally, allowing a larger angular flux per unit longitudinal length (see below). It is also more simple to produce since no fancy machining needs to be performed. In fact for the test experiment reported below, we converted and re-shimmed an existing 46 mm period conventional undulator into a quasi-periodic undulator within three weeks. Note that our magnetic design results in two free parameters η and δ as opposed to the original design which presents a single free parameter η. The δ parameter allows a continuous tuning between a conventional undulator ($\delta = 0$) and a quasi-periodic undulator ($\delta \bullet 0$). One typically uses δ to optimize the suppression ratio on a particular harmonic number of the spectrum. For small values of δ, only the high harmonics are modified whereas for large values all low harmonics are affected . We have selected η = •5 and δ = 5 mm which were optimized to suppress harmonics 3 and 5 of the fundamental at a gap of 20 mm. The total number of periods is 36 and the period is 46 mm. The dimensions of the magnet blocks are 11.4 x 23 x 70 mm.

2.2 Magnetic Field Measurement

Figure 2 presents the measured vertical field in Tesla as a function of the longitudinal coordinate for a magnetic gap of 20 mm. As a result of the vertical displacement of the H-magnets, the peak field oscillates between 0.436 T ±0.5% and 0.499 T ±0.5% excluding the two first and last poles. The corresponding peak deflection parameter is 2.15 which is sufficient to provide a full tunability between harmonics 1 and 3 assuming a conventional undulator.

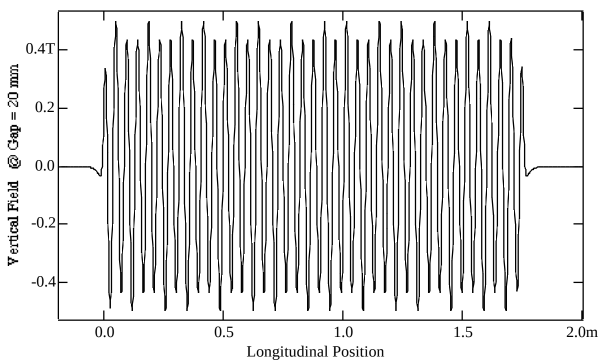

Figure 2 : Measured vertical field of the quasi-periodic undulator as a function of the longitudinal coordinate.

2.2 Radiation Spectrum

Figure 3 presents the angular spectral on axis of a filament electron beam of 6 GeV and 200 mA for three structures computed with B2E[4]. The computation assumes an ideal 3D field which is computed with Radia[5] .

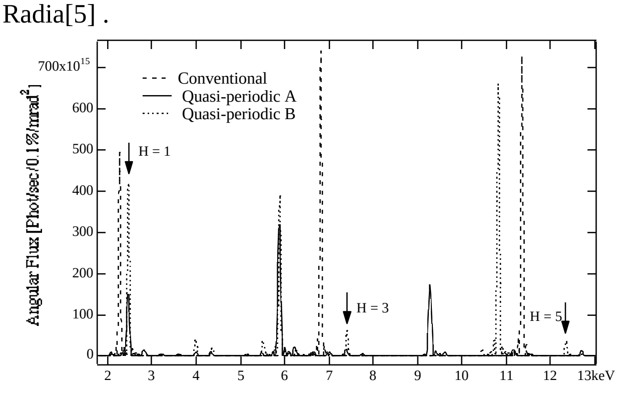

Figure 3 : Angular spectral flux versus photon energy on axis of a filament electron beam of 6 GeV and 200 mA. The spectrum from a conventional undulator is compared with that of two different designs of quasi-periodic undulators all of the same length.

The conventional undulator is a constant period undulator made with δ = 0 mm. The quasi-periodic undulator B is built with the same magnet blocks as the conventional undulator but with the necessary H-magnets displaced by δ = 5 mm. The Quasi-periodic undulator A is that of ref [2][3] built with a longer period in such a way that the energy of the fundamental coincides with that of undulator B. All three undulators are of the same length,1656 mm, and the photon energy of their fundamental is around 2.4 keV for a gap of 20 mm and an electron energy of 6 GeV. In Figure 3, the harmonic 3 and 5 of the quasi-periodic undulators have been marked with an arrow to stress the effect of the quasi-periodicity, namely the removal of the peaks at the energies precisely equal to 3 x and 5 x the energy of the fundamental. Undulator B presents a 2.5 higher angular flux on the fundamental than undulator A! This originates from the higher packing ratio of magnet blocks per unit undulator length. During the manufacture, some shimming was applied to the quasi-periodic undulator . The position in time of the electric field pulses originating from each maxima of the magnetic field were compared (and forced to agree) with those computed from the ideal 3D magnetic field. Within a few iterations a rms. phase error of 5 degrees was reached which is sufficient to expect a negligible perturbation of the harmonics 1 to 5. We believe that with more time, the phase error could have approached the typical 1 degree error routinely achieved in all conventional undulators at the ESRF[6]. Due to the nonperiodicity of the magnetic field, the full numerical simulation of the effect of the ESRF electron beam emittance on the spectrum requires an enormous CPU time especially if one is interested in the high harmonic numbers. This has not been done and was replaced by a real experiment on the ID6 Machine Diagnostic beamline.

3 EXPERIMENT

In order to make an accurate comparison of the spectra produced by a conventional and a quasi-periodic undulator, the newly built quasi-periodic undulator was installed on the ID6 beamline on a revolver structure together with a conventional undulator of the same length and period. Both undulators were built with a different quality of magnet blocks. As a result, for the same magnetic gap, the energy of the fundamental of the quasi-periodic undulator was predicted to be at a slightly lower energy than that of the conventional undulator. The monochromator is made of a single crystal of Silicon 311 diffracting the horizontal plane. It is placed at a distance of 32.2 m from the undulator. The data were recorded at a fixed wavelength by varying the magnetic gap between 22 and 35 mm and integrating into an aperture of 0.1 x 0.1 mm aligned on the undulator axis . The electron beam conditions were those of the 2/3 filling mode of operation , 200 mA and 4 nm (0.04 nm) horizontal (vertical) emittances. The horizontal (vertical) beta function of the source point is 36 m (2.5 m). In order to reach an optimum resolution in the measurement of the undulator spectrum, a small aperture of 0.1 x 0.1 mm was used. Thanks to the revolver structure, within a few minutes, both undulators could be interchanged and the spectral characteristics could be closely compared with the same conditions of electron beam and beamline instrumentation. Figures 5 and 6 present the spectral flux per unit solid angle observed at the fixed energies of 14.2 keV and 23.8 keV as a function of the magnetic gap for both undulators. Due to some experimental constraints, the 14.2 keV was the lowest energy that could be reached in this experiment . It is unfortunately not possible to tune the fundamental to this high energy, nevertheless, one can observe and compares the shapes and intensities of the higher harmonics.

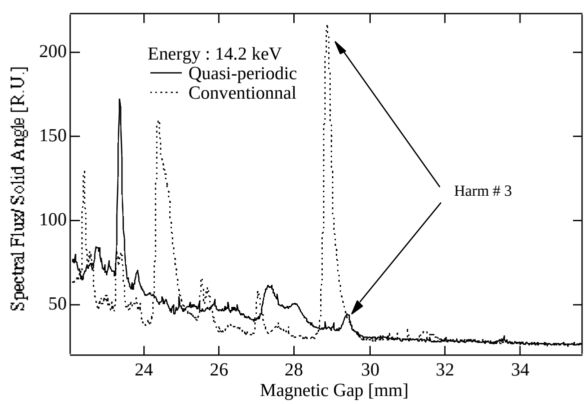

Figure 4 : Spectral flux per unit solid angle vs. magnetic gap observed for a conventional and quasi-periodic undulator of the same length and period at an energy of 14.2 keV.

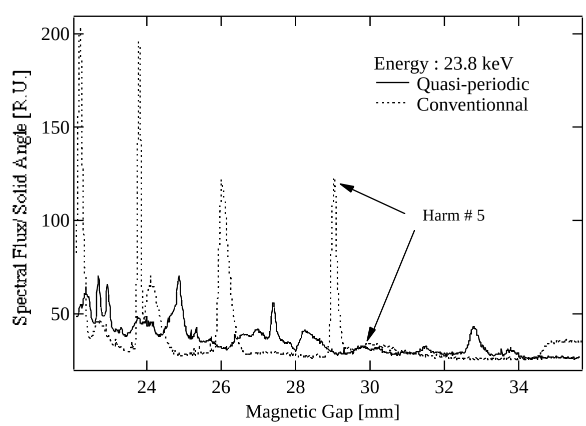

Figure 5 : Spectral flux per unit solid angle vs. magnetic gap observed for a conventional and quasi-periodic undulator of the same length and period at an energy of 23.8 keV.

Comparing the spectra computed with a filament beam based on the measured magnetic field at several gap values, one can predict the magnetic gap of the third (fifth) harmonics when observed at an energy of 14.2 keV (23.8 keV). The results are indicated by the arrows on Figures 4 and 5. The intensity ratio of harmonics 3 (5) between both spectra observed around a gap of 29 mm is 11 (15) which corresponds to a suppression ratio of 8.3 (11.3) when taking into account the 25 % lower intensity of the fundamental of the quasi-periodic undulator (as computed with a filament electron beam). The quasi-periodic undulator spectra shown in Figure 4 and 5 present a complicated set of peaks requiring further interpretation work .

4 CONCLUSION

We have built a 1.6 m long quasi-periodic undulator with a new simple and compact magnetic design which can be optimized by means of two degrees of freedom . With this magnetic design, quasi-periodic undulators can be built without any significant additional complexity and cost as compared to a conventional undulator and with a marginal reduction of the angular spectral flux in the fundamental. The radiation has been recorded on the ID6 beamline and compared to that of a conventional undulator. A spectacular suppression of harmonics # 3 and # 5 is observed confirming the usefulness of quasi-periodic undulators . We also observe that intensity in almost all peaks in the spectrum of the quasi-periodic undulator are lower than the harmonic peaks of a conventional undulator taking place at similar energies, the effect being the most important at high energies. This is expected from the much greater number of peaks present in the spectrum which must roughly share a similar energy integrated angular spectral flux. Awaiting further detailed investigations on this subject, for the moment, we only recommend the use of quasi-periodic undulators for experiments making intensive use of the fundamental harmonic where the penalty in spectral flux is low (20-30%) , the harmonic pollution is usually important and the efficiency of harmonic suppression is optimum. A new quasi-periodic undulator, based on this design but with a 54 mm period is presently under construction for the MEDEA industrial beamline of the ESRF. The fundamental covers the 1-6 keV photon energy range with a large suppression of harmonics 3 to 9.

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[4] The B2E code is freely available for download from« http://www.esrf.fr/machine/support/ids/Public/welcome.html ».

[5] The Radia code is freely available for download from« http://www.esrf.fr/machine/support/ids/Public/welcome.html ». Details have been published in :P. Elleaume, O. Chubar, J. Chavanne, Presented at the PAC97 Conference May 1997, Vancouver. see also P. Elleaume, O. Chubar, J. Chavanne . SRI97, to appear in Journal of Synchrotron Radiation May 1998.

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