BRAINSTORMING ON NEW PERMANENT MAGNET UNDULATOR DESIGNS

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Abstract

Various new permanent magnet undulator designs are presented, including modified quasi-periodic structures capable of generating both circular and linear polarization, as well as other linear and variably polarized schemes with reduced harmonic intensity and on-axis power density. A comparison of the performance of the various schemes is made for the practical application of a low photon energy device for ELETTRA.

1 INTRODUCTION

In general, contamination by higher harmonics of radiation is very harmful for synchrotron radiation experiments. There are several methods to eliminate higher harmonics such as a gas filter, a total reflection mirror, etc. Also, the even harmonics may be eliminated by selecting an appropriate diffraction plane in a crystal monochromator in the x-ray region or by using a laminar type grating monochromator in the VUV region. However, it is not so easy to eliminate lower order harmonics (such as 2, 3) without having an intensity reduction of fundamental radiation.

For the same purpose as we described above, some proposals have been made from the side of the light source. Popik and Vinokurov proposed an undulator to suppress the higher harmonics on axis by adding a horizontal magnetic field [1]. From a totally different point of view, Hashimoto and Sasaki proposed a concept of quasi-periodic undulator (QPU) to eliminate rational higher harmonics but leaving irrational ones [2]. Tanaka and Kitamura proposed a "Figure-8" undulator to reduce on-axis power density by introducing a large horizontal magnetic field having a double period length, hence, leading to the projected electron trajectory of the shape of number 8 in the undulator [3]. Khlebnikov *et. al*. also proposed a non-sinusoidal field undulator to reduce on-axis power density [4]. Recently, Sasaki proposed a crossed EPU for generating a linearly polarized radiation with no higher harmonics on axis [5], and Diviacco and Walker examined the possibility of a quasi-periodic elliptically polarizing undulator in a new scheme [6].

In this paper, we compare three different types of undulators capable of generating a radiation with reduced harmonic intensity and on-axis power density. The first device is called "APPLE-8", which is capable of generating both circular and linear polarization with reduced on-axis power density. The second consists of a combination of vertical and horizontal magnetic fields with different period lengths to reduce the power density and the intensity of higher harmonics on axis. We have called the device "PERA", Italian for pear, because of the shape of projected electron velocity. The third is a modified quasi-periodic undulator based on a conventional periodic undulator.

2 PRINCIPLES AND MAGNETIC STRUCTURES

In this section, we see what type of magnetic field distribution is required for each device, and examine possible magnetic structures.

2.1 APPLE-8

This device consists of magnet rows having two different period lengths and an APPLE type motion mechanism [7]. By changing the magnet row phase, various types of radiation are generated. In the case of APPLE-8, at a position of zero magnet row phase, the horizontal magnetic field has twice the period length of the vertical magnetic field equivalent with the Figure-8 undulator [3]. At a certain finite magnet row phase, this device is capable to generate a magnetic field as follows:

$$B_x = B_0\left\{\cos(2\pi z/\lambda_1) + \cos(2\pi z/\lambda_2)\right\} \quad (1)$$

$$B_y = B_0\left\{\sin\left(2\pi z/\lambda_1\right) - \sin\left(2\pi z/\lambda_2\right)\right\} \quad (2)$$

where $\lambda_1=2\lambda_2$. An electron beam draws a quasi-helical trajectory in the field described above.

Figure 1 shows a schematic drawing of possible configuration of APPLE-8.

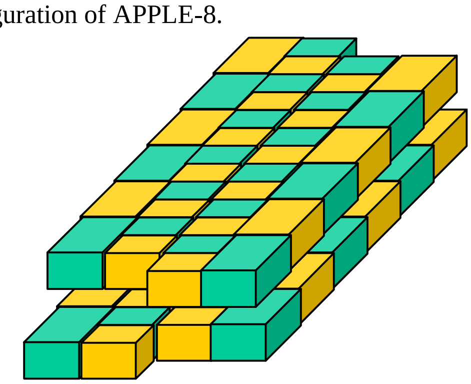

Fig.1: Schematic drawing of magnet configuration of APPLE-8. Finite magnet row phase case.

2.2 PERA

This device has no magnet phase motion mechanism and is designed to generate linear polarization with fewer higher harmonics. Figure 2 shows a schematic drawing of PERA. The magnetic structure of this device is similar to the Figure-8, but with a different combination of period lengths. Furthermore, in the middle rows generating vertical field, every three longitudinally magnetized block has a reduced height and an opposite direction of magnetization [8]. Outer rows generate horizontal magnetic field on the undulator axis.

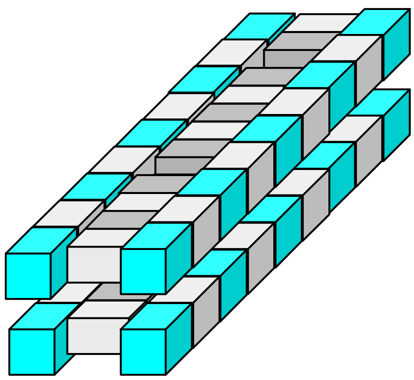

Fig. 2: Schematic drawing of PERA undulator.

The magnetic field generated by this device can be well simulated by equations below:

$$B_x = -B_{x0}\sin(2\pi z/\lambda_x), \tag{3}$$

$$B_y = B_{y0}\left\{\frac{1}{2}\cos(2\pi z/\lambda_{y1}) + \frac{3}{2}\cos(2\pi z/\lambda_{y2})\right\}, \tag{4}$$

Here, $\lambda_{y1}=2\lambda_x$ and $\lambda_{y2}=2\lambda_x/3$.

2.3 Modified QPU with new scheme

Here, we introduce a new parameter, *r*, for creating a one-dimensional quasi-periodicity as shown in the equation below [9]:

$$z_m = d'\left\{m + \left(\frac{r}{\eta}-1\right)\left\lfloor\frac{1}{r\eta+1}m+1\right\rfloor\right\}, \tag{5}$$

and $d/d'=r/\eta$. Here, *m* is an integer, η is an irrational number, *d* and *d'* are shorter and longer inter-pole distance, respectively. The bracket $\lfloor x \rfloor$ stands for the greatest integer less than x.

An original basic structure of a QPU is realized by aligning positive and negative magnet poles alternately at the 1D quasilattice points designated by Equation (5). In this paper, however, we use a new scheme to construct a QPU instead of using an original structure. In order to simulate the inter-pole distance "*d*" described above, we remove horizontally magnetized block or replace to a shorter height block to introduce lower peak magnetic field at the appropriate positions in a conventional undulator having a half period length *d'*. The positions are described by the rule of creation of quasi-periodicity.

Figure 3 shows a possible configuration of QPU in new scheme.

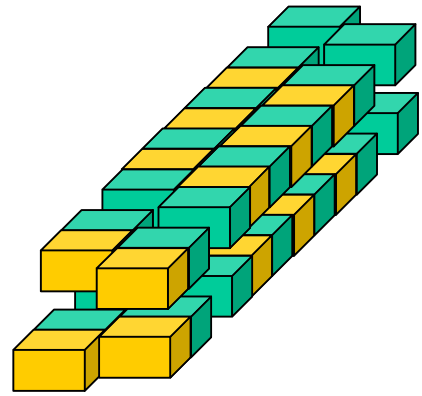

Fig. 3: Schematic drawing of Elliptically Polarizing QPU in new scheme.

By introducing an APPLE-type motion mechanism in a QPU in new scheme, this device is capable of generating both linear and circular polarization with no rational higher harmonic radiation.

3 RADIATION PROPERTIES

For each device, parameters were carefully selected for obtaining a low photon energy of around 10 eV for a specific experiment at ELETTRA. Calculations of radiation spectra have been made by using the storage ring parameters listed in Table 1.

Table 1: ELETTRA parameters used for the calculation

Electron energy	*E* [GeV]	2.0
Beam current	*I* [mA]	100
Natural emittance	ε_0 [nm-rad]	7
Emittance coupling	κ [%]	1.3
Energy spread	*dE/E* [%]	.08
Horizontal β	β_x [m]	8.2
Vertical β	β_y [m]	2.6

Figure 4 shows an on-axis brilliance spectrum of APPLE-8 undulator in a circular polarization mode. The period lengths of outer and inner rows were assumed to be 240 mm and 120 mm, respectively. Total length of this device was assumed to be 2 m due to the limitation of available length in a straight section of ELETTRA storage ring. Low order higher harmonics (2, 3, 4, etc.) are existing even for a circular polarization mode as shown in Fig. 4. For a linear polarization mode, the radiation spectrum is identical with a Figure-8 undulator. For both polarization modes, on-axis power densities are much smaller than that of planar undulator.

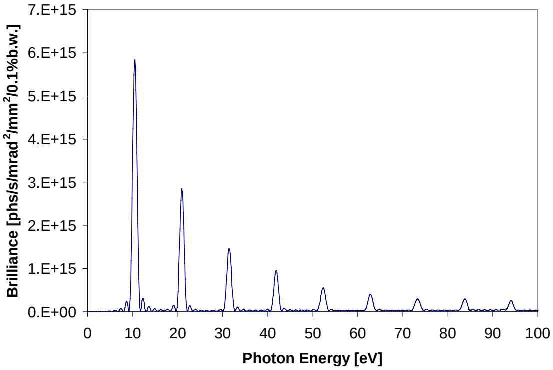

Fig. 4: Brilliance spectrum of APPLE-8 undulator. Circular polarization mode.

Brilliance spectrum of PERA undulator is shown in Fig. 5. As mentioned above, the PERA undulator generates only a linear polarization. On-axis power density of this device is slightly smaller than that of Figure-8 undulator.

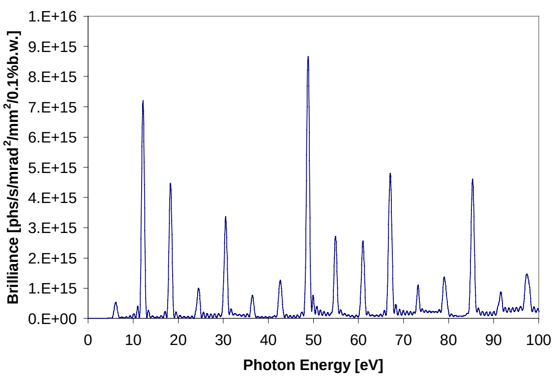

Fig. 5: Brilliance spectrum of PERA undulator.

The period length λ_{y1} of 240 mm, λ_{y2} of 80 mm, and λ_x of 120 mm were assumed for the calculation.

Figure 6 shows a brilliance spectrum of new QPU in a linear polarization mode.

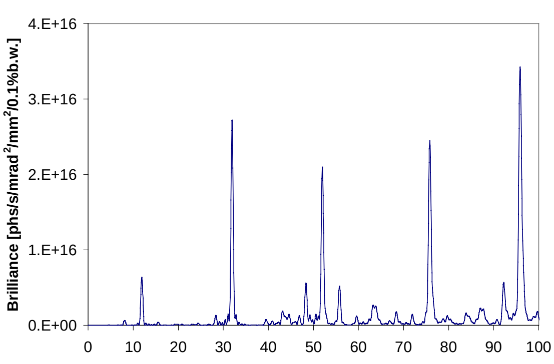

Fig. 6: Brilliance spectrum of a new QPU. r=1.4, $\eta = \sqrt{15}$.

A half period length, corresponding to *d'* in QPU, was assumed to be 60 mm. Total length of this device was assumed to be 2.28 m. For the calculation, *r*=1.4 and $\eta = \sqrt{15}$ were assumed for this particular example. These parameters were selected to minimise the intensity at 2nd and 3rd harmonic positions in a radiation through a pinhole of 0.7x0.7 $mrad^2$ aperture. The resulting flux spectrum is shown in ref. [10].

4 CONCLUSIONS

A brief comparison among three different devices was made for a specific experiment at ELETTRA. For the purpose of lower on-axis power density in the linear polarization mode, APPLE-8 and PERA might be good solution. However, they both generate rational harmonics of low order. APPLE-8 and a new QPU are capable of generating circularly polarized radiation. However, a radiation from APPLE-8 includes rational harmonics even in a circular mode. As far as the magnet structure is concerned, APPLE-8 and PERA are too complicated. A new QPU has the simplest structure and is capable of being converted back to an original periodic APPLE structure by replacing a few magnet blocks.

In conclusion, for the purpose of experiment of low photon energy with fewer rational harmonics in both linear and circular polarization, the new QPU is the best choice. Furthermore, by changing a set of parameters for creating a 1D quasi-periodicity, we can move peak positions of irrational harmonics toward a required direction using this extra degree of freedom. Therefore, it is possible to design the best magnet configuration for any kind of users' experiments.

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