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TRIPLE PERIOD UNDULATOR

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Abstract

Insertion devices are one of the key components of modern synchrotron radiation facilities. They allow for generation of radiation with superior properties enabling experiments in a variety of disciplines, such as chemistry, biology, crystallography and physics to name a few. For future cutting edge experiments in soft and tender x-rays users require high flux and variable polarization over a wide photon energy range independent of other desired properties like variable pulse length, variable timing or Fourier transform limited pulses. In this paper, we propose a novel ID-structure, called Triple Period Undulator (TPU), which allows us to deliver a wide energy range from a few tens of eV to several keV at the same beamline with high flux and variable polarization. The TPU are particularly interesting in context of BESSY III, the successor facility of BESSY II.

INTRODUCTION AND MOTIVATION

Synchrotron radiation is crucial for a variety of scientific applications. Modern synchrotron radiation facilities, based on linacs or storage rings utilize undulators to deliver radiation of variable polarization and wavelength according to the experimental requirements. The fundamental wavelength of the radiation generated in an undulator depends on the electron beam energy, undulator period and undulator field strength. For wavelength tuning, these parameters have to be varied. Changing the beam energy is not an option for storage rings, since all insertion devices in the ring are fed with the same beam. A strong reduction of the magnetic field strength can be easily facilitated by opening the undulator gap. This results in a shorter radiation wavelength up to the limit $\lambda = \lambda_u/(2\gamma^2)$, where λ_u is the undulator period and γ the Lorentz factor of the beam, but it also reduces the photon flux significantly. Short-period variable-gap undulators with small minimum-gap offer a solution and are therefore popular in modern storage rings. Their short period length allows the generation of radiation with short wavelength with moderate or low electron beam energies, while the high field strengths obtained at the small minimum gaps enable the generation of radiation with longer wavelengths. Thus, they extend the photon spectrum for users in a cost efficient manner. The state of the art devices for minimising period length and maximising peak field strength with permanent magent materials is the in-vacuum crryogenic permanent magnet undulator (CPMU). Such devices are installed in several synchrotron facilities such as Diamond Light Source in the UK, Swiss Light Sources and SOLEIL in France, delivering radiation in X-ray range.

Very recently, a 17 mm period CPMU with a 5.5 mm minimum operational gap (CPMU17) was installed in BESSY II ring [1]. It was designed and built by HZB as a part of the canted double undulator system for the new Energy Materials in-situ Laboratory (EMIL) at BESSY II [2]. EMIL is also served by a 48 mm period APPLEII undulator (UE48), built at HZB. The double undulator system covers an energy range from 60 eV to 6000 eV.

UE48 provides radiation with variable polarization, whereas the CPMU17 delivers radiation with a fixed polarization like the other already-existing in-vacuum cryogenic undulators. In order to transfer the in-vacuum cryogenic technology to devices with variable polarization, HZB has developed the key components for an in-vacuum APPLE II undulator in a dedicated R&D project [3,4]. The fabrication of a full scale in-vacuum APPLE II undulator with a period length of 32 mm (IVUE32) has been already launched within the ATHENA project [5]. Although the IVUE32 is a room temperature device, the layout is designed to facilitate the introduction of cryogenic magnets. Thus, it serves as a prototype for the cryogenic in-vacuum APPEL device envisaged in the ATHENA project. While the IVUE32 will be installed in BESSY II storage ring, serving two Resonant inelastic X-ray scattering (RIXS-) and one microscopy beamline, the planned cryogenic in-vacuum APPLE will be installed in SINBAD center for short innovative bunches and accelerators at DESY.

However, to meet the demands of future cutting-edge experiments in the soft and tender X-rays, variable polarized high flux synchrotron-radiation with superior properties in a wide energy range from a few tens of eV to several keV has to be delivered to the same beamline. This is only possible, if the period length of an installed undulator can be changed fast and without any interruption of the accelerator operation. A fast and rather simple possibility for changing the undulator period is provided by the so called revolver type undulators [6–11]. Their period-changing mechanism usually consists of a pair of pivot-mounted rotating cylinders, on which the magnetic structures with different period lengths are mounted. An in-vacuum revolver type device based on this concept was built already in 2003 [9]. Frequently, improved and optimized fixed polarization devices of this type are being studied and constructed [7,8,10].

Recently, an in-air double APPLE II structure with period lengths of 180 mm and 55 mm was built and installed at the Canadian Light Source [11]. In this device, the magnet structures are mounted side by side on a plate that can be moved transversely on a stiff girder in order to change the period length. This way, one avoids the phase and angular errors due to the rotation mechanism, but has to deal with the permanent presence of the full magnetic forces of the two

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structures. Force compensation concepts, such as developed for IVUE32 [4], can mitigate this effect significantly.

Taking advantage of the R&D on in-vacuum cryogenic and APPLE II undulators carried out by HZB, we propose a Triple Period Undulator (TPU), consisting of three side-by-side mounted APPLE structures that can be moved transversely, to change the period length. As in-vacuum cryogenic devices, the TPU will generate variable polarized high flux synchrotron-radiation. When fed by an electron beam with an energy of between 2 GeV to 2.5 GeV, it delivers radiation in soft and tender X-ray range. In this paper, we discuss the benefits of and the R&D required for such a device.

BENEFITS OF TPU

A comparison of the performance of TPU and conventional undulators is shown in Fig. 1a, which shows the brilliance of the radiation as a function of photon energy for the undulators installed in BESSY II and a TPU installed in a possible BESSY-II successor with reduced horizontal emittance of 200 pm rad (instead of the current BESSY II value of 5 nm rad) but the same beam energy. In this case the TPU consists of three 4.5 m long Apple-II type magnetic structure with periods 52 mm, 22 mm and 15 mm and a minimum gap of 4 mm. The TPU not only extends the energy range towards tender X-rays, it also provides continuously high flux in a photon range from less than 100 eV to 2500 eV. Please note that the combination of a suitably prepared mirror installed opposite to a movable frame containing two conventional grating and a multilayer coated grating [12, 13] can be used to extend the operational range of the beamline to the same range [14]. Assuming a slightly higher beam energy of 2 GeV, the desired photon energy range can be covered with fundamental undulator radiation, as shown in Fig. 1b. The TPU in combination with the reduced horizontal emittance and higher beam energy delivers radiation in soft and tender X-ray, see Fig. 2. Of course, higher beam energy shifts the entire spectrum, as clearly visible in Fig. 2. Therefore, the period lengths of TPU and the beam energy have to be matched to cover the desired photon energy range.

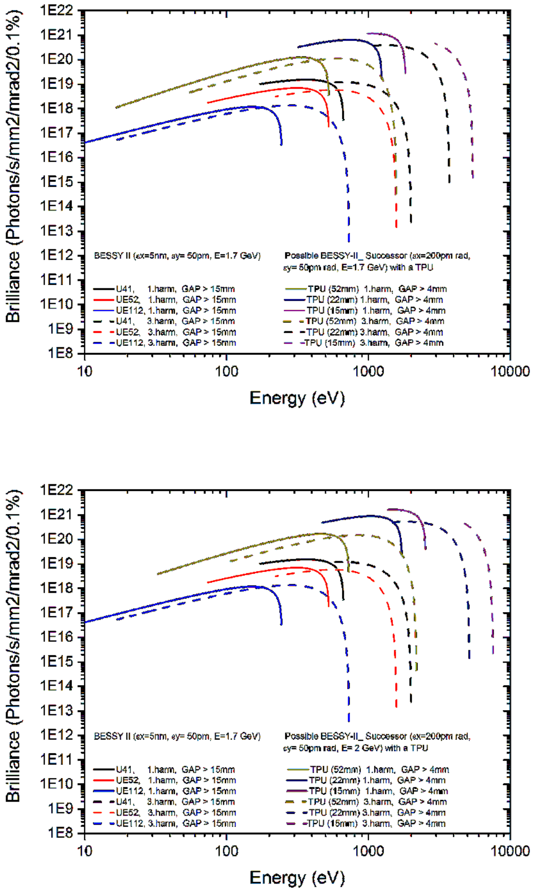

Figure 1: The brilliance of the radiation as a function of photon energy is depicted for existing undulators at BESSY II and a 4.5 m long TPU with periods 52 mm, 22 mm and 15 mm at a a) 1.7 GeV BESSY-II-Successor (top) and b) 2.0 GeV BESSY-II-Successor (bottom) with reduced horizontal emittance. The horizontal emittance is reduced form 5 nm rad to 200 pm rad.

NEEDED R&D

As discussed above, in a magnetic device consisting of three side-by-side mounted APPLE-II structures, one has to deal with permanent presence of magnetic forces. This is particularly true for small gap in-vacuum devices. Therefore, the TPU has to take advantage of the forces compensation concept described in [3]. This, however, implies an increase in the transverse dimensions of the keepers for each individual APPLE structure, as the keepers have to accommodate both the main magnets and the compensation magnets. Basically, the transverse keeper size is doubled, as the transverse dimensions of the main and compensation magnets are roughly the same [3]. For a given period length the magnet field on axis is constant for transverse magnet dimensions larger than 20 mm, as shown in Fig. 3. The transverse dimension of undulator magnets is usually constrained by the need for a wide, flat, good field region. This is to ensure that the undulator behaves as a constant optical element during large beam excursions, such as those seen during off-axis injection or innovative operational modes like TRIB [15, 16]. A good field region of ±20 mm can be met in a planar device with 60 mm wide magnets, which might naively imply a 30 mm wide magnet block requirement for an APPLE device. However APPLE II devices will always suffer from an on-axis dip in the transverse field profile [Fig. 4], an effect that is enhanced as the operational gap decreases. In the past, various compensation schemes for dynamic and static multipoles such as L-shims [17] have been used to mitigate the consequences for the accelerator operation. For TPU, new compensation concepts have to be developed, since, for example, iron L-shims can not be implemented.

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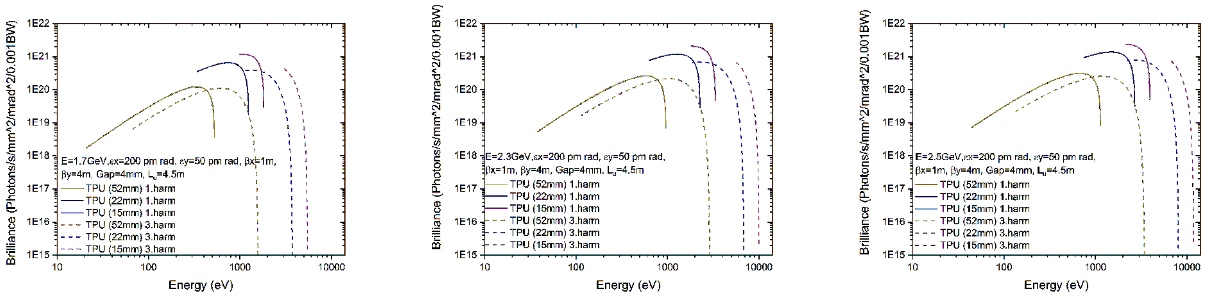

Figure 2: The brilliance of the radiation as a function of photon energy is depicted for a TPU consisting of three 4.5 m Apple-II type magnetic structure with periods 52 mm, 22 mm and 15 mm and a minimum gap of 4 mm. For the calculation a horizontal emittance of 200 pm rad, a vertical emittance of 50 pm rad and three different beam energies 1.7 GeV, 2.3 GeV and 2.5 GeV have been assumed.

Assuming, for instance, a transverse magnet block size of $30 \times 30\,\mathrm{mm}^2$, the transverse structures have to be shifted on the order of a few tens of centimetres, to change the period. Considering that the magnet rows of the individual APPLE structures also have to be movable, this shift is certainly a technical challenge which needs to be addressed.

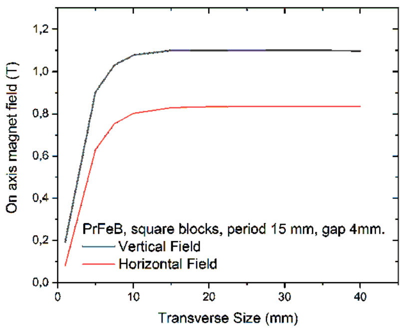

Figure 3: The magnetic field as function of the transverse size of the magnet blocks is shown. For the calculation PrFeB magnet blocks with square cross-section at 77 K, a period length of 15 mm, a gap of 4 mm and a row separation of 0.5 mm have been assumed. The code RADIA [18] is used for the calculations.

Additionally, the taper section connecting the accelerator vacuum chamber to the in-vacuum TPU is certainly very challenging. Particularly, because simulation codes capable of modelling the complex layout and calculating the corresponding impedances are very rare and demand excessive CPU resources. The mandatory low-impedance design and construction of this section needs to be flanked by dedicated experimental impedance studies.

Furthermore, there are crucial technical developments needed for this compact design that have for instance to address gap and shift motion, attachable and detachable flexible tapers, in-situ gap and shift measurements, liquid N_2 system, magnet field measurements (in-vacuum and cooled) to name a few.

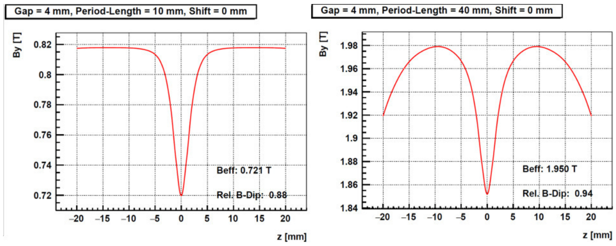

Figure 4: The transverse profiles of the magnet field for two different period lengths of 10 mm (left) and 40 mm (right) are depicted. For the calculations square magnet blocks of $30 \times 30\,\mathrm{mm}^2$ and a gap of 4 mm have been assumed. The reduction of the field on center is due to the transverse gap of 0.5 mm between magnet rows in an APPLE device. The code UNDUMAG [19] is used for the calculations.

CONCLUSION

We propose the triple period undulator, an in-vacuum device consisting of three side-by-side mounted APPLE structures that can be moved transversely, to change the period length. It will provide variable polarized high flux synchrotron radiation in a very wide energy range. When fed by an electron beam with an energy of approximately 2 GeV to 2.5 GeV, it delivers radiation in soft and tender X-ray range. In this paper, we discussed the benefits of the TPU and the R&D required for such a device.

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