POSSIBLE SUPERCONDUCTING INSERTION DEVICES WITH PERIOD LENGTH DOUBLING FOR BEAMLINES OF THIRD GENERATION LIGHT SOURCES

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Abstract

The tunability of an insertion device can be increased by period length switching, which in superconducting insertion devices (IDs) can be achieved by reversing the current in a separately powered subsets of the superconducting windings. The feasibility of this concept has been experimentally proven.

We study here different possibilities to tailor the needs of beamlines of third generation light sources: FEM simulations performed to compute the magnetic field on axis of such devices with different period lengths are reported together with the spectral simulations.

INTRODUCTION AND MOTIVATION

At ANKA we are running an R&D program to develop superconducting insertion devices (IDs). Superconducting insertion devices (SCIDs) with respect to the state of the art permanent magnet technology IDs have a higher K value at a given period length and a definite gap.

A significant feature of IDs is the possibility to enhance the tuning range and functionality considerably by period length switching. This becomes apparent when looking at the standard undulator equation [1]

$$\lambda = \frac{\lambda_U}{2\gamma^2 n}\left(1+\frac{K^2}{2}\right), \text{ with } K = \frac{e}{2\pi m_e c}\lambda_U B_y \quad (1)$$

where λ is the wavelength of the photons emitted at the n-th harmonic, e is the electron charge, m_e the electron mass, c the speed of light and $\gamma = E/m_e c^2$ is the Lorentz factor with E being the energy of the electron beam . The wavelength of emitted photons can be changed by varying the undulator magnetic period length λ_U, the magnetic field amplitude on axis B_y, and the beam energy E. The most common way is to vary the field amplitude B_y, because it is technically more challenging to vary the undulator period and the electron beam energy E. This is the standard tuning procedure for all kinds of IDs. In permanent magnet undulators this is realized by varying the gap. For superconducting IDs the electric current is changed.

A more effective way is to vary the period length λ_U [2].

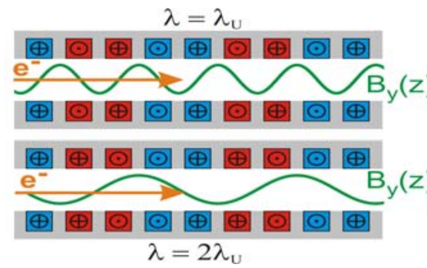

Figure 1: Sketch of the principle of period length switching (period doubling).

So it is possible to further increase the tuning range. Using permanent magnet technology this is realised in the so-called revolvers [3], interchanging more magnetic structures mechanically. A typical revolver at the ESRF includes a multi-purpose undulator (period 32mm to 35mm) tuneable in a large energy range between 2 and 30 keV and a second smaller period assembly dedicated to optimum operation (higher brilliance) in limited photon energy ranges (period 17mm to 27mm). The idea on how to realise period length switching in SCIDs was first described in [4]. The case of period length doubling is shown in Fig. 1. Here red and blue indicate two separate powerable circuits, circles with points and with crosses mark the current directions, and the magnetic field z-dependence in y-direction $B_y(z)$ on axis is schematically illustrated in green. To switch the period length one has to invert the current direction in one of the two circuits (red or blue).

At ANKA we proved for the first time the feasibility of period length switching for superconducting IDs using a 9 pole mock-up designed and manufactured by BNG and showing that there is no need to retrain the magnet after each switch [5]. In order to use only one power supply instead of two for the two circuits, reducing the thermal input to the device, work is ongoing at ANKA to develop a superconducting switch [6].

In this contribution we report investigations performed to study different applications of period doubling in superconducting IDs to tailor the needs of beamlines of third generation light sources. We have first computed the magnetic field on axis of IDs with different period length using finite element method (FEM) simulations and we have then simulated their spectral performance.

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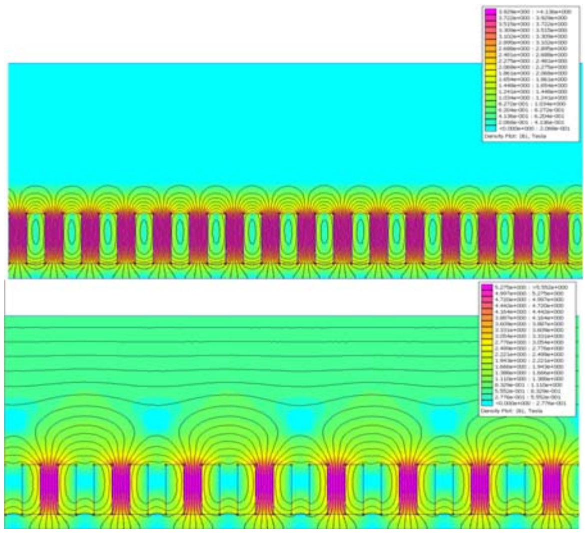

Figure 2: 2D coloured magnetic density plot for a gap of 8mm, λ_U = 14mm (fundamental on top) and λ_U = 28 mm (doubled at bottom).

FEM MODEL AND SIMULATIONS

For the FEM simulations the 2D open source software FEMM (Finite Element Method Magnetics by David Meeker, http://www.femm.info/wiki/HomePage) has been used. Starting point for modelling was the design of the superconductive undulator/wiggler device (SCUW) mock-up utilized for the measurements reported in [5]. A similar model was created in FEMM. First a magnetic period length of λ_U =15mm and a magnetic gap of 8 mm was chosen. The groove and pole width was 3.75 mm and the pole height was 10mm. The grooves were filled completely with the conductor. Therefore the winding cross section of the conductor in the groove was 3.75mm x 10mm. The current density in the groove was set to 1050 A/mm^2 and C10 steel was used as yoke.

For all other simulations the period length λ_U was gradually changed in a range from 8 to 16 mm. The ratio between pole and groove width has always been kept 50%. We have calculated the magnetic field on axis for three different magnetic gaps: 4mm, 6mm and 8 mm. All other input variables were not modified and stayed the same for all simulations. With these parameter sets each simulation was performed twice, for each of the cases shown in Fig. 1: once with alternating current direction in each successive groove and once with doubled periodicity. The results of the FEM simulations for a magnetic gap of 8 mm and the two period lengths λ_U of 14 mm (fundamental) and 28 mm (doubled) are presented in figure 2.

The extension of the tunability range by period length doubling is demonstrated in figure 3, where the gap value for the performed simulations is plotted against K (left) and against the maximum peak field on axis (right). The coloured open circles refer to the fundamental period length while the filled circles in the same colour to the doubled one.

SPECTRAL CALCULATIONS AND RESULTS

We have calculated the spectral performance of SCIDs for a third generation light source taking into account the benefit of period doubling and considering the demands of possible beamlines applications. The calculations were made considering the beam parameters of the DIAMOND light source: beam energy E = 3.0 GeV, beam current I = 300 mA, energy spread $\Delta E/E$ = 0.001, horizontal ε_X = 2.74 nmrad and vertical ε_Y = 0.0274 nmrad emittance, horizontal β_X = 4.8 m and vertical β_Y = 1.43 m beta function. In figure 4 the brilliance for a period length of 13mm (red curves) and 26mm (blue lines) respectively with a magnetic gap of 6mm, corresponding to a vacuum gap of 5mm, is plotted against the photon energy. For this parameter combination the calculated spectrum of the SCID includes a variety of energy regions of scientific interest.

The spectrum for λ_U =26mm displayed in blue is covering a region from 0.450keV up to 25keV, which is the standard range for X-ray absorption spectroscopy (XAS) experiments, covering the K-edges from S to Sn, and up to the L-edge of U, enabling speciation studies of catalytically and environmentally important elements like Sulfur. . For photon energies up to 4keV the K-edge of Si

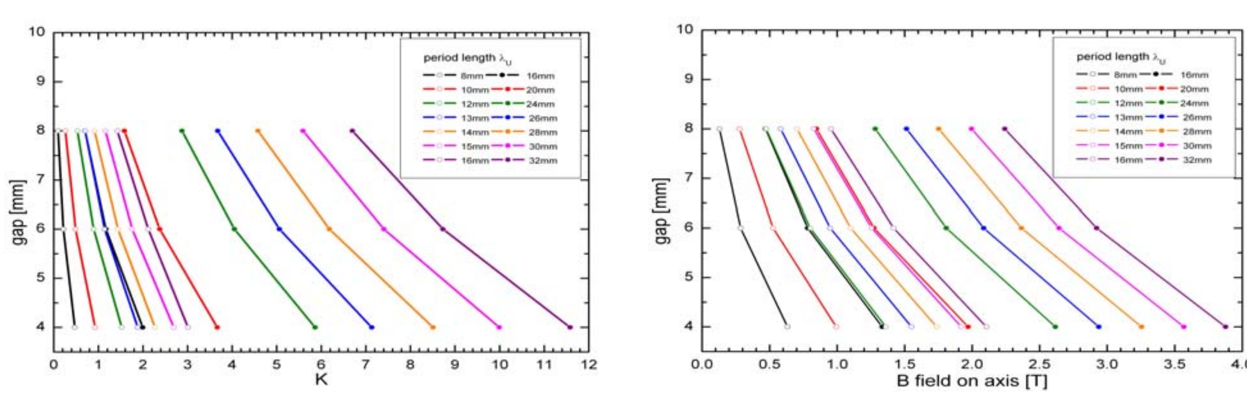

Figure 3: Gap versus K value (left plot) and gap as a function of the maximum B field on axis (right plot). Each for different period lengths.

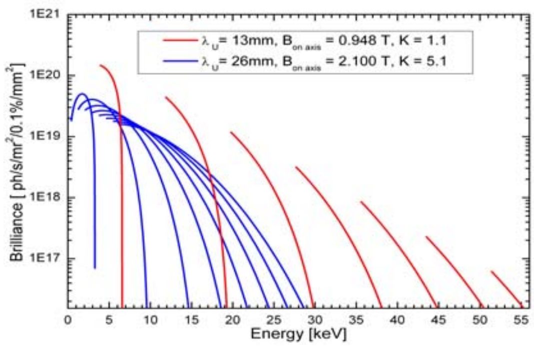

Figure 4: Brilliance plotted against photon energy.

(at 2.5keV), S (at 2.8 keV) or Cl (at 3.6keV) can be examined. In the energy regime between 10 and 13 keV the K-edge of Ge (at 11.1keV) is located. The K-edge of Mo is at 20keV. For all these K-edges the ID with doubled period length can bridge the gaps in the spectrum of the fundamental period length (red curves).

With the period length λ_U =13mm the brilliance is increased in specific energy ranges relevant for scientific investigations by one up to several order of magnitudes. Various X-ray spectroscopy methods can be used in the energy range 4-6 keV of the first harmonic. Some of the experiments performed at the ID 26 beamline at the ESRF using these methods are: XAS on Cr-doped V_2O_3, [7], X-ray Absorption Near-Edge Structure (XANES) on Ca on the Mn_4Ca-complex of oxygenic photosynthesis [8] and X-ray emission spectroscopy (XES) for ligand identification in Ti-complexes [9]. The third harmonic, which ranges between 11.6 and 16.5keV, covering the absorption edges of relevant elements in proteins as Cu, Zn, Se or Pb [1], is of scientific interest for macromolecular crystallography [10,11]. The energy range of the third harmonic of the 13mm period length device covers as well nuclear resonance scattering experiments for the isotopes ^{57}Fe and ^{73}Ge [12]. The higher harmonics from 25 keV to 50 keV can be used for X-ray fluorescence (XRF) and X-ray diffraction (XRD) [13].

CONCLUSION

Period length switching extends the tunability range of an insertion device by enlarging the range of the *K* values of the ID. Starting from the calculations presented for different examples of period length doubling in SCIDs it is possible to calculate the spectral performances in different machines and tailor an ID to meet the needs of a particular beamline. An attractive solution for a synchrotron in the middle energy range as DIAMOND, with period length doubling from 13mm to 26 mm, has been presented.

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