EXPERIMENTAL DEMONSTRATION OF PERIOD LENGTH SWITCHING FOR SUPERCONDUCTING INSERTION DEVICES

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Abstract

One of the advantages of superconducting insertion devices (IDs) with respect to permanent magnet IDs is the possibility to enhance the tuning range and functionality significantly by period length switching. Period length switching can be achieved by employing two or more individually powerable subsets of superconducting coils and reverse the current in a part of the windings.

In this contribution we report the first experimental test of this principle demonstrated on a 70mm NbTi mock-up coil with period tripling, allowing to switch between a 15mm period length undulator and a 45mm wiggler (SCUW 15/45).

INTRODUCTION

According to the basic undulator equations [1]

$$\lambda = \frac{\lambda_U}{2\gamma^2 n}\left(1 + \frac{K^2}{2}\right) \tag{1}$$

$$K = \frac{e}{2\pi m_e c}\lambda_U B_y$$

where e is the electron charge, m_e the electron mass and c the speed of light. The spectral range which can be covered by the emitted photons depends on the undulator period length λ_U and the magnetic field amplitude on axis B_y. Where λ is the wavelength of the n-th harmonic.

The highest reachable photon energy for a given harmonic is fixed by the undulator period and the relative electron energy γ, and the tuning range depends on the achievable field amplitude B_y.

A demand for high photon energies on the one hand and wide tuning ranges on the other hand have contradictory influence on the magnetic design. As one can see from eq. 1, in order to preserve a tuning range given by a certain maximum *K*-value, shifting to shorter period lengths requires a higher field amplitude, which is technically harder to achieve the shorter the period length is.

One way out is to change of the period length instead of varying the field amplitude [2], which is however for permanent magnet devices technically not easy to realize. In case of superconducting undulators (SCUs) the solution is the combination of the conventional method of field amplitude tuning combined with a period length switching in steps [3, 4].

To achieve this goal one has to reverse the current direction in one subset of the superconductive winding packages. The basic case is proposed in [4] and sketched in fig 1.

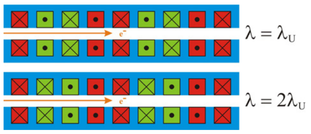

Figure 1: Most simple example for period length switching (period doubling).

Points and crosses indicate the current directions. To switch the period length one has to invert the current direction in the green winding packages.

SCUW 15/45

A superconductive undulator/wiggler device (SCUW) is foreseen for the planned IMAGE beamline at ANKA. The SCUW will allow to use in one device the high brilliance of the undulator from 6 to 15 keV for imaging, and the wiggler mode for higher photon energies to perform phase contrast tomography.

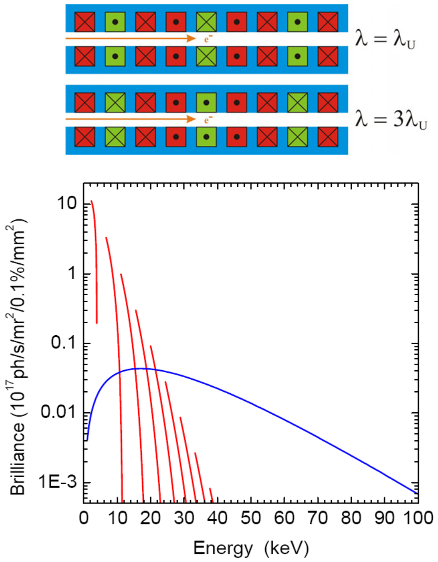

Figure 2: Winding scheme for period tripling and calculated tuning curve and brilliance spectra for the planned SCUW.

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This requirements can be fulfilled by period tripling of the undulator mode of a SCU 15 as shown in fig.2 [5].

It is shown the tuning curve and the brilliance for the SCUW device with 15mm undulator period and 45mm wiggler period length after period tripling. We have considered the SCUW in a straight section of the ANKA storage ring with the following parameters: beam energy E=2.5 GeV, beam current I=200mA, energy spread $\Delta E/E$= 0.1%, horizontal ε_x=41nm rad and vertical ε_y=0.3nm rad emittance, horizontal β_x= 14.7m and vertical β_y= 1.9m beta function. For the magnetic field we have used the values shown in table 2 for 8mm gap. To change over between the two modes one has to change current direction in the green circuit (see Fig. 2).

Table 2: Design parameters for the hybrid superconducting undulator/wiggler (SCUW) mock-up for ANKA.

	Undulator		Wiggler	
Period length [mm]	15	15	45	45
Number of periods	99	99	33	33
Magnetic gap [mm]	5	8	5	8
Max. field B [T]	1.46	0.77	4.34	3.21
K_{max}	2.05	1.08	18.2	13.5

To verify the feasibility of period switching, a 70mm mock-up has been designed and produced by our collaborating partner Babcock Noell GmbH (BNG).

SCUW Test coil

The mock-up is one coil which consists of 10 plates with 10 poles and 9 grooves fully wound. This arrangement corresponds to 4.5 undulator and 1.5 wiggler periods respectively (see fig 4).

As yoke material C10 steel is used and clamping of the plates is done by two end plates pressed together by stud bolts. Before clamping, the plates were aligned on the straight side. The grooves are wound with round NbTi wire of 1.05mm diameter with insulation, over 500 superconducting filaments embedded and a copper to superconductor ratio of 1.4.

At the end it is soldered to superconducting wire bundles to make the connection to current leads stable and avoid damaging. To achieve the above mentioned values for the field amplitude and the K-value in the different operation modes the superconductor has to carry currents of 765A in the wiggler mode and 1100A in the undulator mode.

MEASUREMENT SETUP

Fig. 3 presents a schematic view of the main components of the magnetic measurement setup for superconducting mock-up coils, CASPER (**C**haracterization **S**etu**P** for field **E**rror **R**eduction), a liquid helium bath cryostat. Details can be found in [6].

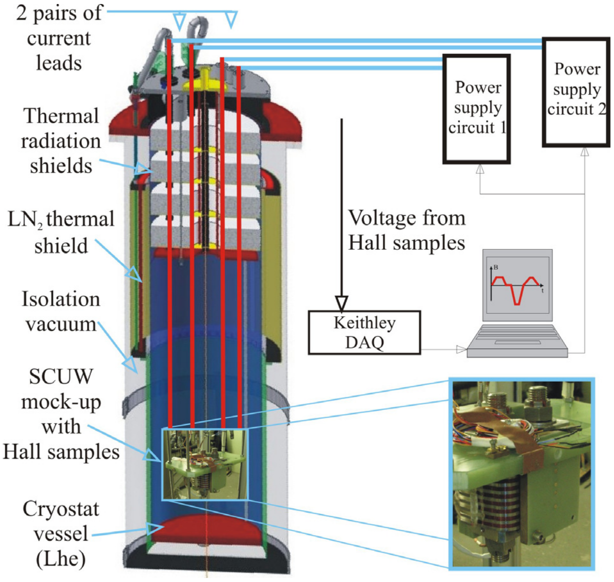

Figure 3: Schematic drawing of the cryostat system with the SCUW mock-up and Hall sample holder.

First we tested the undulator mode, then warmed up the system, change connection to the wiggler mode and cooled down again. As indication for the different operation modes we clamped 3 Hall samples on a glass reinforced plastic (GRP) plate and fixed this at the edges with distance pieces to the coil. The distance to the poles was set to 3.75mm. The Hall samples have been placed above the individual poles (2, 5 and 8) as shown in fig 4. The crosses on the samples indicate that a field vector pointing into this surface yields to a positive field.

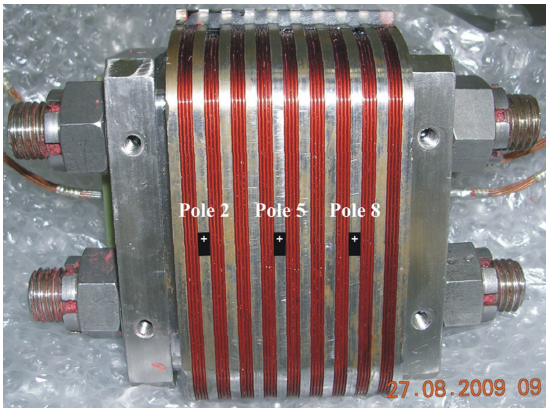

Figure 4: SCUW test coil with sketch of the Hall sample placement.

As indicated in the winding scheme in fig. 2, the field direction and the amplitude change after changing the mode of operation. The two power supplies are computer controlled. The Hall voltage is measured with a Keithley

2700 and the Hall current is provided by a Keithley 6220 precision current source.

RESULTS

The first training was performed with the two circuits soldered at the magnet splice and powered by only one power supply. With this solution, switching is possible only after warming up, modifing the circuit and cooling down again. During training we had the first quench at 510A in undulator mode and 849A in the wiggler mode respectively. After a few more quenches we reached 1147A and 1055A for undulator and wiggler corresponding to engineering current densities in the grooves of 1052A/mm^2 and 968A/mm^2. The highest ramp rate was 350A/min in both modes.

Essential for the operation of a SCUW device is to demonstrate that the period switching works without going through a thermal cycle. To show this, we connected one power supply with 1500A maximum current to each of the circuits and ramped them simultaneously. A change from one mode to the other was accomplished by interchanging the current leads of one power supply and hence the polarity in this circuit. Following such procedure the time between ramping in the two different modes is about 5 minutes.

The measurement sequence was started by ramping to 1100A and down to zero in the undulator mode continuing with a sweep to 1000A in the wiggler mode both with a ramp rate of 422A/min (fig. 5). This yields to engineering current densities in the winding packages of 1007A/mm^2 and 915A/mm^2 respectively.

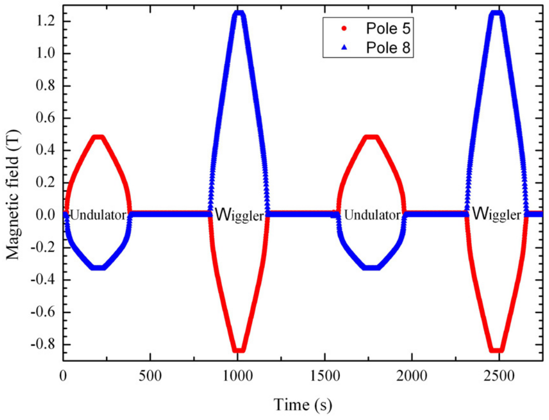

Figure 5: Measured local field at selected poles with opposite field directions with time.

The two curves in fig. 5 present the change of the field in direction and amplitude for the two modes at pole 5 and 8. We proved that it is possible to switch the period length, without need of training the magnet again after each switch.

In fig. 6 we compare the value of the field amplitudes shown in fig. 5 with the simulations performed with RADIA [7] for one single coil.

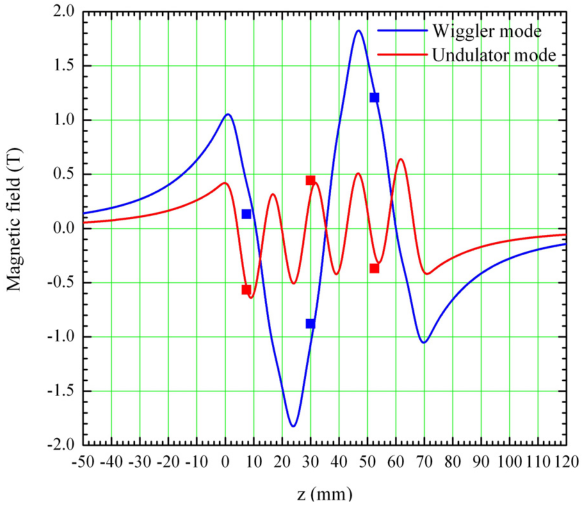

Figure 6: Comparison between calculated field with RADIA (lines) and locally measured maximum field amplitudes (squares) for the two operation modes of the SCUW 15/45.

The lines show the calculated field distributions along the coil at a distance of 3.75mm from the poles in the two modes and squares indicate the measured local field values taken from fig. 6. The differences between measurements and simulations are mainly due to the error made in positioning the Hall samples to the middle of the poles (z-direction ± 250µm) and to the distance to the coil (3.75mm ± 150µm). Considering the errors performed in the Hall samples alignment, fig. 6 shows a satisfying agreement between simulation and measurements.

CONCLUSION

In this contribution we confirm the feasibility for period switching of a superconducting hybrid undulator/wiggler device by means of measurements on a 70mm, 9 grooves SCUW mock-up. The training was performed up to enigineering current densities of 1052A/mm^2 (undulator) and 968A/mm^2 (wiggler) with ramp rates up to 422A/min. The locally measured fields while switching match satisfyingly to numerical simulations.

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