DEVELOPMENT OF THREE NEW SUPERCONDUCTING INSERTION DEVICES FOR THE ANKA STORAGE RING

C. Boffo, M. Borlein, W. Walter, Babcock Noell GmbH, Würzburg, Germany
S. Casalbuoni, A. Grau, M. Hagelstein, R. Rossmanith, Institute for Synchrotron Radiation, Research Center Karlsruhe, Germany
E. Mashkina, B. Kostka, E. Steffens, University of Erlangen-Nürnberg, Germany
A. Bernhard, P. Peiffer, D. Wollmann, T. Baumbach, University of Karlsruhe, Germany

Abstract

After a first successful test of a superconducting cold bore undulator in the synchrotron light source ANKA [1] a new generation of superconducting insertion devices are under construction or in a detailed planning phase at ANKA in collaboration with Babcock Noell GmbH (BNG). The first one, called SCU15, now under construction is an improved version of the existing undulator (15 mm period length, 100.5 full periods long, cold bore). The improvements are: less heat load from the beam to the superconducting coils and a reduced field error. The period length of the second device called SCUW can be switched electrically between 15 and 45 mm. The third one is a superconducting undulator which can tolerate a beam heat load of several Watts in combination with a small field error. This undulator is named SCU2. It is designed for third generation light sources. In this paper the technical concepts of the three projects are summarized.

INTRODUCTION

The superconducting undulator SCU14 installed in ANKA in 2005 as a demonstrator has been in operation since that time without interruption. Thanks to this experience two main areas of further improvements were identified [1].

1.) Since the measured beam heat load to the cold surface is higher than expected [2] [3] a design was developed which reduces the beam generated heat load on the superconducting coils. The performance of the coils is extremely dependent on temperature gradients.
2.) The field errors are related only to mechanical tolerances. This is different to permanent magnet undulators where field errors are related to mechanical tolerances <u>and</u> variation in the magnetic strength of the individual magnets. In order to reduce the field errors the mechanical tolerances have to be improved or shimming techniques have to be developed [4].

The superconducting undulators now under construction or in a detailed planning stage will integrate step by step these new concepts.

SCU15

SCU15 is a 15 mm period length, 100.5 period long undulator. In principle this is an improved version of the existing SCU14 installed in ANKA. The two requirements, reduced heat load for the superconducting coils and better field quality are solved in the following way.

Beam heat load reduction

The concept aiming to reduce the heat load to the superconducting coils is shown in Fig. 1.

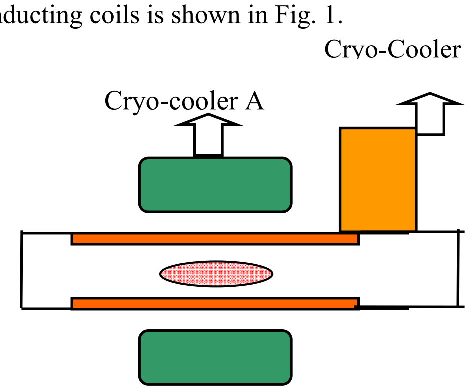

Fig. 1 Schematic of the inner part of the undulator. Surrounding the beam (in black) is a 300 µm thick stainless steel vacuum chamber (liner) with a high quality Cu coating in the vicinity of the beam (50 µm thick). The heat produced by the beam in the Cu layer is transported to the Cu blocks positioned sidewards of the beam. The Cu blocks are connected to a Cryo-cooler. The superconducting coils (green) are thermally separated from the liner and are independently cooled by cryo-coolers. The connection to the cryocoolers are marked by arrows.

The design shown in Fig. 1 is based on a concept originally developed for superconducting wigglers at BINP [5]. The temperature in the liner is higher than the foreseen 4.5 K of the coils. In between the liner and the coils the heat transfer is inhibited. Both parts are cooled by separate cryo-coolers. The cooling efficiency of the cryocoolers increases with temperature.

The heat produced by the beam is transported through the liner to the cryo-cooler without reaching the coils. The crucial point is the heat transport due to possible contacts between coils and liner. A detailed study is at the moment under way with goal of identified the optimal configuration.

Another chance to reduce the sensitivity of the undulator with respect to the heat load of the beam is to use a less temperature sensitive wire, e.g. Nb_3Sn. First tests with a mock-up (Fig. 2) were performed and will be continued in the near future. The aim is to study how the complex heat treatment of the wire acts on the phase error of the undulator. Similar tests were performed earlier in Berkeley [6] and Argonne [7].

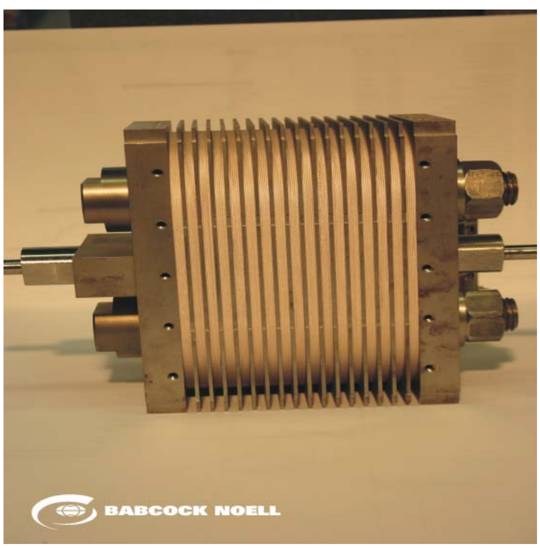

Fig. 2 Nb_3Sn Undulator mock-up before heat treatment.

The tests showed that the used Nb_3Sn wire can transport currents up to 2200 A/mm^2 in simple test devices like solenoids consisting of a few windings. The maximum current density in the Nb_3Sn mock-up shown in Fig. 2 was limited to about 1000 A/mm^2. The design will be improved in future prototypes.

Reduction of field errors

In order to obtain a superconducting undulator with a low field error detailed statistical analysis on the mechanical tolerances were performed. The aim is to obtain for the planned SCU15 a phase error of 3.5 degrees. The phase error (see Fig. 3) is determined by three mechanical tolerances:

a.) Tolerances in the period length
b.) Tolerances in the position of the pole relative to the beam axis
c.) Tolerances of the wire position relative to the pole

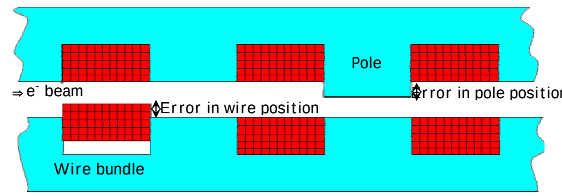

Fig. 3 Possible mchanical errors contributing to the phase error in a superconducting undulator: errors in the pole position and errors in the position of the wire relative to the pole.

In the following it is assumed that the mechanical tolerances for a.). b.) and c.) are 10 µm (3 sigma). The phase error for 1000 configurations are calculated under the assumption that the mechanical tolerances are randomly distributed. The distributed mechanical tolerances contribute differently to the resulting phase error. The resulting phase error distribution is summarized in table I. The strongest contribution to the phase error is correlated to the tolerance in the period length (a) followed by the tolerance of the pole position (b).

Table I: The influence of mechanical errors on the phase errors for 1000 SCU15 configurations [4].

	Phase error in degrees
Peak of distribution	0.7
75 % level	1.6
97 % level	4.5

The phase error can be reduced when the influence of one or two tolerances on the phase error can be eliminated, for instance by measuring and machining the poles before winding the wire.

The mechanical tolerances for the SCU15 are specified for a phase error of less than 3.5 degrees. In the case that this goal is not reached and the phase error is too high a wire shimming system can be applied [4].

SCUW

SCUW is a device which allows to switch between a 15mm period length undulator and a 45mm wiggler. A detailed description of this concept can be found in [8]. The basic concept is described in figure 4. The SCUW has two separate windings marked by red and yellow in Fig. 4. By reversing the current in the yellow winding the period length is changed from 15 mm to 45 mm.

At the moment first studies are under way to find an acceptable solution for the matching end periods for both operational modes. The construction of a prototype is in preparation.

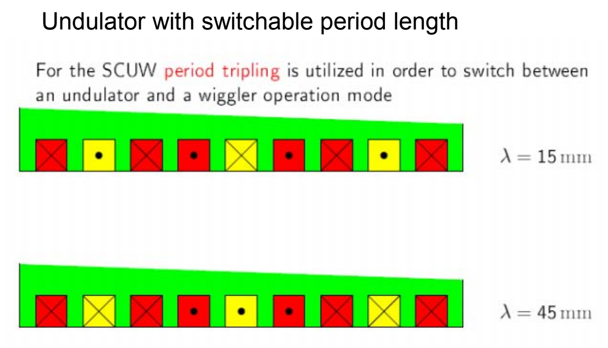

Fig. 4 The Undulator / Wiggler SCUW with an electrically switchable period lengh from 15 mm to 45 mm. The period length is switched by reversing the current in the yellow marked windings.

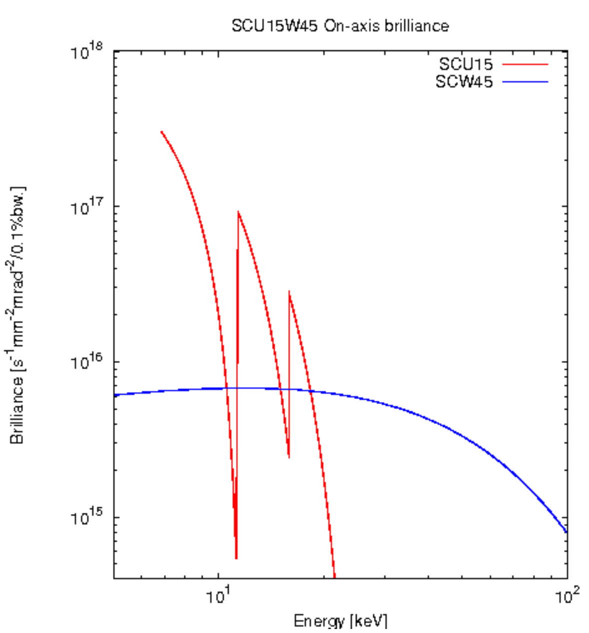

Fig. 5 Calculated brilliance of a 15/45 mm period length undulator /wiggler for the storage ring ANKA. The stored current is assumed to be 200 mA.

Fig. 5 shows the calculated brilliance for ANKA. In the undulator mode the maximum photon energy is 20 keV, in the wiggler mode about 100 keV.

SCU2

SCU2 is an advanced undulator for a third generation light source. SCU15 and SCUW are test undulators which are tailored to the needs of ANKA. ANKA is filled with beam at 500 MeV. The beam energy is afterwards ramped to 2.5 GeV. Injection and acceleration is at the moment only possible when the beam stay clear is larger than 12 mm. The gap width during undulator operation is 7 mm or even less. This means that the gap has to be opened during injection and acceleration. This is from a mechanical point of view very demanding and makes the device in the case of ANKA complicated. Synchrotrons with a full energy injector do not necessarily need this feature.

The bunch length at ANKA is about 10 mm and comparable to 3rd generation synchrotrons relatively long. Since the dominating heat source in the undulator is the heating by image currents shorter bunch lengths and higher currents cause higher beam heat load. Therefore the SCU2 will be designed to tolerate beam heat loads up to 6 W.

The SCU2 will also have a small phase error. This means that shimming concepts will play a more central role in the design. As already mentioned conventional active shimming techniques with additional superconducting wires are under consideration which will allow to reduce the phase error significantly (see [4]). Tests of these and other shimming concepts are at the moment tested in one of the test cryostats at ANKA [9].

REFERENCES

[1] S. Casalbuoni et al., Phys. Rev. ST Accel. eams 9, 010702 (2006)
[2] S. Casalbuoni et al., Phys. Rev. ST Accel Beams, 10, 093202 (2007)
[3] E. Wallen and C. LeBlanc, Cryogenics 44, 879 (2004)
[4] D. Wollmann, this conference http://accelconf.web.cern.ch/accelconf/
[5] S. Krushchev et al., Proc. RuPAC 2006, Novosibirsk http://accelconf.web.cern.ch/accelconf/
[6] S. H. Kim et al., Proc. PAC 2005, Knoxville http://accelconf.web.cern.ch/accelconf/
[7] S. Prestemon et al., Proc. PAC 2003 http://accelconf.web.cern.ch/accelconf/
[8] A. Bernhard et al., this conference http://accelconf.web.cern.ch/accelconf/
[9] E. Mashkina et al., this conference http://accelconf.web.cern.ch/accelconf/