OPERATION OF THE ANKA SYNCHROTRON LIGHT SOURCE WITH SUPERCONDUCTIVE UNDULATORS *

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Abstract

Following the successful performance of a beam test with a superconductive undulator at the synchrotron light source ANKA there are plans to equip most of the straight sections with superconductive undulators. In this paper the first results of the measurements are presented and future plans are summarized.

INTRODUCTION

The figure of merit of an undulator is the maximum field which can be obtained at a given period length and a given gap [1]. The field strength of permanent magnet undulators is limited by the properties of the material. The field strength can be increased by about 30 % by cooling them to cryogenic temperatures [2].

Several years ago using different approaches both Brookhaven [3] and Karlsruhe [4] proposed replacing the permanent magnets by superconducting wires. ANKA built the first undulator in a cryostat and tested it with beam in Mainz at the microtron MAMI [5]. Afterwards, in collaboration with ACCEL Instr. GmbH a small prototype was built which demonstrated that the achievable fields exceed the fields of the permanent magnet undulators significantly [6]. Finally, an undulator with a cryostat was built for a storage ring and the device was installed at ANKA.

THE TEST RESULTS OF THE SUPERCONDUCTIVE UNDULATOR IN ANKA

A schematic drawing of the undulator and the cryostat is shown in Fig. 1. The coiling technique has already been described in several previously published papers [7].

The cryostat consists of two different vacuum systems: the beam vacuum system which is connected to the ring vacuum and the insulation vacuum system which thermally insulates the cold mass from the ambient temperature. The two vacuum systems are separated at the undulator by a 300 µm stainless steel foil. A 30 µm copper layer is sputtered on the inner side of the foil. The whole system is cooled by 3 two-stage Sumitomo cryo-coolers without liquid He.

The gap can be adjusted to three different widths: 16, 12 and 8 mm. During injection the undulator is opened to 25 mm. This feature allows ANKA to be filled without any problems (the beam is injected at an energy of 0.5 GeV and afterwards accelerated to 2.5 GeV with a short halt at 1.6 GeV). The maximum storable current at ANKA is 200 mA.

The aim of the test was to demonstrate that the undulator can be run under normal operational conditions. The storage ring is filled (under normal circumstances) twice a day and the lifetime is about 15 to 20 hours depending on the current.

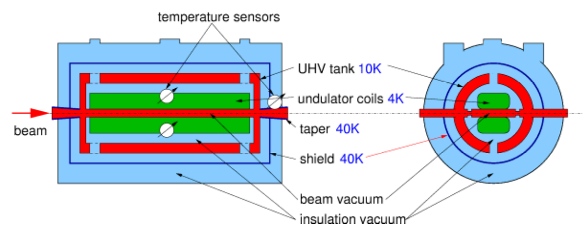

Figure 1: Schematic drawing of the undulator and the cryostat. The green parts show the undulator coils: period length 14 mm, 100 periods. The red part is the beam vacuum system and the blue part the insulation vacuum. The white dots mark the position of the temperature sensors (one at each coil and one at the taper).

The undulator is protected from synchrotron radiation produced in the down-stream bending magnets by a collimator system located 1m upstream of the undulator. The collimator consists of four scrapers: two horizontal and two vertical, which can be moved independently.

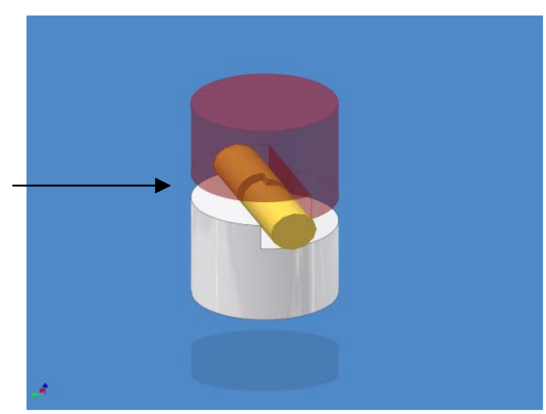

Figure 2: Schematic drawing of the collimator system, 1 m upstream of the undulator. The arrow marks the direction of the beam. The four arms of the collimator can be moved independently. The drawing shows the collimator in the closed position

*Work partly supported by the German BMBF grant # 806033/7 and the EU grant JR4, 6th EU framework program
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The collimator is opened during injection at 0.5 GeV and closed step by step during energy ramping. As expected, the outside horizontal collimator has the biggest influence on the temperature of the undulator. It protects the inner part of the undulator from the synchrotron radiation produced by the last bending magnet in front of the undulator.

Fig. 3 shows how the temperature of the undulator coil is influenced by the beam current. At the beginning of the measurements the beam current was 170 mA. The measurements were performed with the two temperature sensors (fig. 1) positioned at the center of the coils.

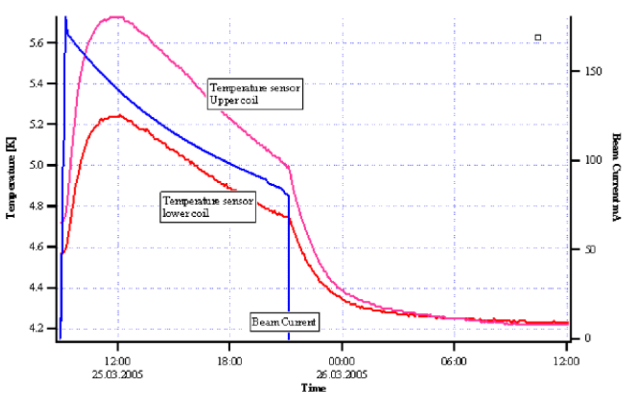

Figure 3: Temperature rise of the coils caused by the beam. The temperature is measured with the sensors in the center of the coils shown in fig. 1. The beam current at the beginning is about 170 mA, beam energy 2.5 GeV. The gap width is 12 mm.

The temperatue rise of the coils is 0.6 and 1 K according to Fig. 3. The difference in the temperature stems from the fact that the beam does not go through the vertical center of the undulator during these particular measurements. The gap width was 12 mm.

In principle, the beam can cause the temperature of the undulator to rise via three different mechanism:

- heating by synchrotron radiation by the upstream bending magnet(s)
- heating by the synchrotron radiation produced by the undulator
- heating by resistive wall effects.

It was shown by various experiments that the last two effects are small. In a first set of experiments a study was made of the temperature rise as a function of the beam energy. It was shown that the temperature rise greatly depends on the beam energy. This indicates that synchrotron radiation bypasses the collimator and heats the undulator. A beam energy independent temperature rise would be a sign that the heating is caused by resistive wall effects. In another experiment the influence of synchrotron radiation produced by the undulator itself was studied. It was observed that the temperature in the coils was almost identical with and without a current through the undulator. This shows that the synchrotron radiation produced by the undulator itself does not warm the undulator.

The statement would also seem to be valid for the coils. There are some indications that the taper undergoes a minor degree of heating by the current. In addition, as one would expect, misalignment of the undulator axis and the beam axis results in warming of the downstream taper by synchrotron radiation..

Fig. 4 shows the measured beam profile 8.3 m downstream of the undulator. The first measured spectra for different k-values are shown in Fig. 5 (logarithmic scale).

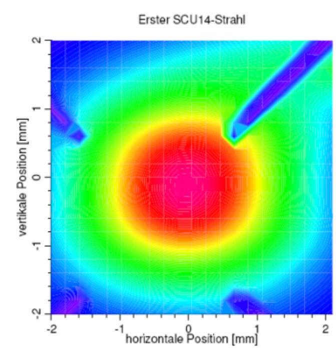

Figure 4: first measured beam profile 8.3 m downstream of the undulator. The four pins aiming at the center of the beam are the shadows of a photon beam position monitor upstream of the intensity detector.

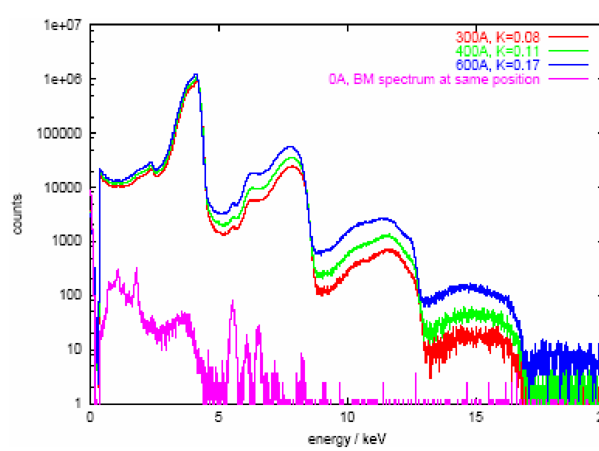

Figure 5: First measured spectra obtained by the undulator at various currents through the undulator (logarithmic scale).

FUTURE SUPERCONDUCTIVE UNDULATORS IN ANKA

The first successful test of a superconductive undulator in ANKA initiated considerations to install three superconductive undulators in the four long straight section. Each of these new devices will demonstrate a different advantage of the superconductive undulator technology.

In one of the straight sections a slightly modified version of the undulator described in the previous chapter will be installed.

For the second straight section a so-called planar helical undulator will be developed [8]. This undulator offers two advantages as both the wavelength as well as the polarization direction can be tuned electrically. The schematic layout is shown in Fig. 6.

The so-called planar helical undulator consists of two undulators: a helical-type undulator which produces a horizontal and a vertical field, and a planar undulator located inside the helical undulator. The latter produces a vertical field. Both undulators are connected to different power supplies so that the horizontal and vertical fields can be influenced independently. As a result, this device can operate as an undulator producing light with switchable helicities and as a planar undulator producing light with horizontal and vertical polarization. The switch from one polarization direction and the selection of the wavelength is performed electrically without any mechanical changes.

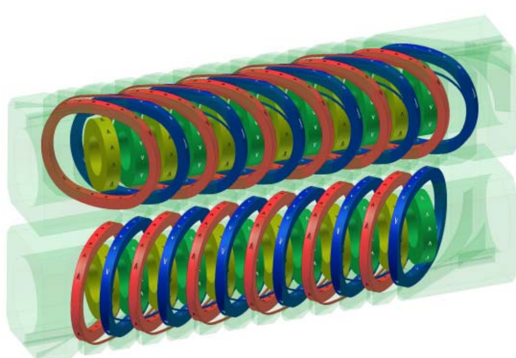

Figure 6: Planar helical undulator with variable polarization direction.

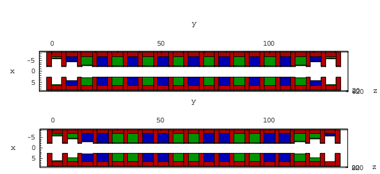

Figure 7: Superconductive undulator with an electrically changeable period length. The rectangular squares mark superconductive filaments. Different colors symbolize different current directions. The red frame consists of magnetic iron. The current directions are changed electrically.

The third straight section will be equipped with a so-called superconductive wiggler / undulator. The basic idea is sketched in Fig. 7.

By changing the current directions the initial undulator with a given period length (upper figure) is converted into an undulator with a double period length (lower figure).

By optimizing the structure of the undulator with one additional power-supply the undulator can be transformed into a wiggler. This is demonstrated with the help of the the brilliance curves of this device shown in Fig. 8.

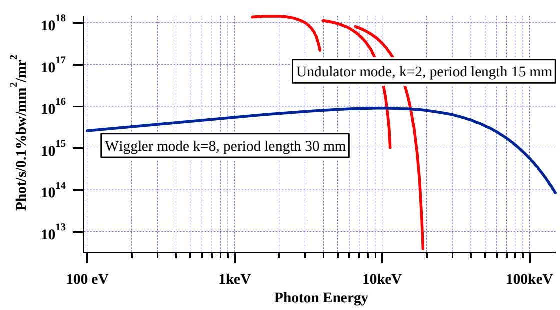

Figure 8: Electrically switchable wiggler / undulator unit.

Doubling the period length of an undulator is not only of interest for a switchable wiggler / undulator configuration but also for a versatile undulator which covers a wide spectral range.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. Reinhard Maschuw and Prof. Volker Saile from Karlsruhe, Prof. Herbert O. Moser from the National University of Singapore, Dr. Pascal Elleaume from the ESRF and Prof. Jochen Schneider from DESY for support and numerous discussions. The authors also have to thank Dr. Th. Schneider and Dr. M. Kläser from the Institute for Technical Physics in Karlsruhe for many contributions concerning the planar helical undulator.

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