A YEAR'S EXPERIENCE WITH A SUPERCONDUCTING UNDULATOR IN THE STORAGE RING ANKA *

R. Rossmanith[#], S. Casalbuoni, M. Hagelstein, B. Kostka, A.-S. Mueller, Forschungszentrum Karlsruhe, Germany
F. Schoeck, E. Steffens, M. Weisser, University of Erlangen-Nürnberg, Germany
R. Frahm, B. Griesebock, U. Haake, University of Wuppertal, Germany
A. Bernhard, D. Wollmann, T. Baumbach, University of Karlsruhe, Germany

Abstract

In March 2005 a superconductive undulator was installed in ANKA and since that time has been in operation [1]. The cryogen-free superconducting undulator was warmed up for one day one year later for routine maintainance of the cryocoolers. The results of the first ever beam tests of a superconducting undulator in a storage ring are summarized in this paper including the obtained spectra and the measurements on the heat load from the beam. The values obtained are so promising that a new undulator with improved performance will be built for ANKA and installed in two years from now.

UNDULATOR PARAMETERS AND BEAM OPTICS

The parameters of the superconductive undulator installed in ANKA are:

Period length: 14 mm
Number of periods: 100
Gap: (in steps variable) 8, 12 and 16 mm

During injection and energy ramping the undulator gap can be opened to 25 mm. In this position the undulator cannot be powered.

The undulator has a cold bore. The undulator is cryogen free and is cooled with 3 Sumitomo 1 W cryocooler. (RDK-408D@50 Hz). The device was built by ACCEL Instr. GmbH in Bergisch Gladbach, Germany.

During the last few years the ANKA beam optics was modified to allow the installation of low gap insertion devices without significantly reducing the life-time of the beam. Fig. 1 shows the modified beam optics for a quarter ring. The insertion devices are installed in the long straight section at the position 0 and 27.6 m in the drawing. The horizontal emittance is 45 nm (calculated with WinAgile [2]). In all cases the vertical emittance measured by an in-air profile monitor [3] is less than 1 % of the horizontal emittance. The dispersion in the long straight sections is not zero.

The vertical beta function in the center of the insertion devices is 1.9 m (horizontal beta-function 14 m).

Fig. 2 shows the measurement of the vertical aperture for the 1.9 m optics in comparison with the previously used optics. The measurements show that with a gap of 8 mm the life-time is not significantly reduced, with a gap of 5 mm it is reduced to about 70 % of the maximum value.

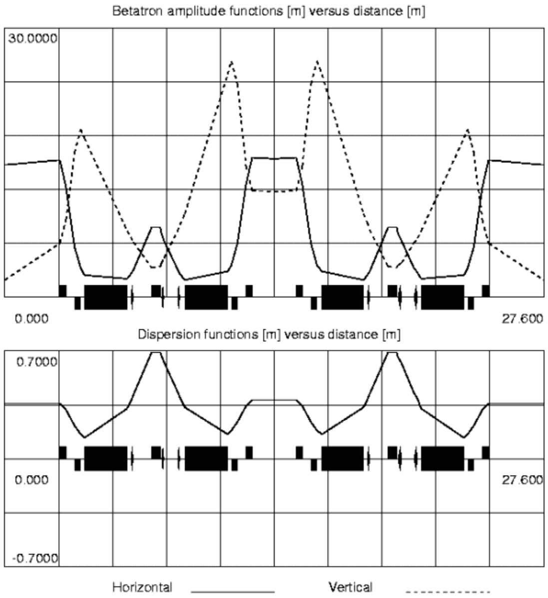

Fig. 1: Beta functions and dispersion for the modified ANKA optics with a minimum vertical beta of 1.9 m in the center of the long straight sections. The horizontal emittance is about 45 nm, the vertical emittance is less than 1% of the horizontal emittance.

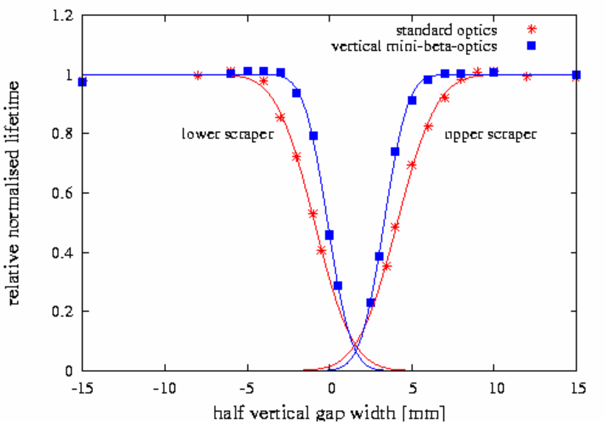

Fig. 2: Measurement of the vertical beam profile with a scraper ca. 2 m away from the center of the long straight section. The figure shows that with a vertical beta function of 1.9 m an operation with a 5 mm gap and a reduced life-time seems to be possible, an operation with 8 mm gap does not significantly reduce the lifetime.

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[#] rossmanith@anka.fzk.de

The scraper system is about two meters away from the point with the minimum beta. The measurements clearly indicate that the beam is not in the center.

At the moment a dedicated undulator operation with a gap of 5 mm with reduced life-time seems to be possible but the preferred solution is a lower vertical beta with a beta of 0.7 to 0.9 m. Therefore, the two quadrupoles in front of and after the undulator will be replaced by a triplet.

THE MEASURED SPECTRA

For the first time ever, the spectra of a superconducting undulator in a storage ring were measured. Fig. 3 shows the spectra obtained at 2.5 GeV (normalized to 100 mA beam current) in comparison with the spectra calculated from the magnetic field measurements. The calculations were performed with the help of the program SRW [4]. The agreement is excellent at lower photon energies. At higher photon energies the Si(111) channel cut monochromator might be the reason for the difference. The measurements will be continued in the near future with an improved monochromator system.

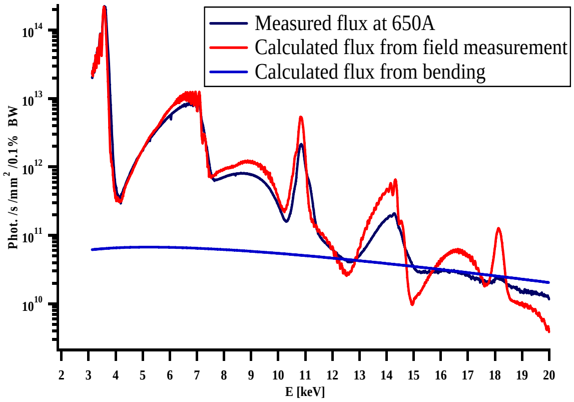

Fig. 3: Logarithmic spectrum measured with a Si(111) channel-cut monochromator [5] in comparison with both the calculated spectrum from field measurements and the spectrum produced by a bending magnet. The obtained undulator spectrum is about two to three orders of magnitude higher than the bending magnet spectrum (undulator gap 8 mm, k=0.56).

The linear spectrum is shown in fig. 4. The second harmonics is weaker by a factor of 10 and its width is determined by the emittance of the beam and the geometry used during the measurement.

In order to study the spectra at different emittances, the beam energy was varied (the emittance scales with γ^2). A linear spectrum measured with a commercially available Si photodiode at 1.3 GeV is shown in fig. 5. The measurements were performed without a monochromator and therefore the line width is determined by the resolution of the photodetector. The horizontal emittance for this energy is about 10 nm. The 5th harmonics can still be seen in this picture as a tiny peak close to 5 keV.

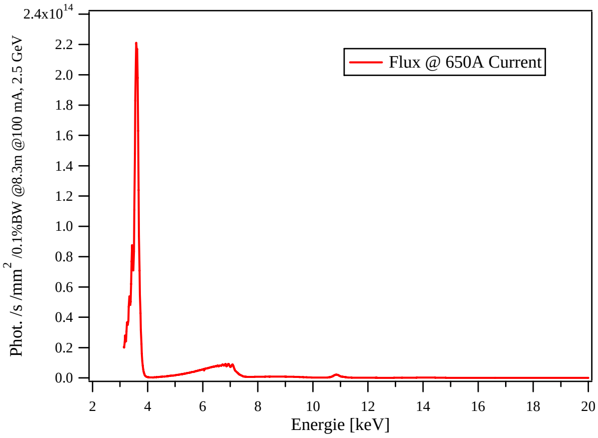

Fig. 4: Linear spectrum measured with a Si(111) monochromator at 2.5 GeV. Gap width 8 mm.

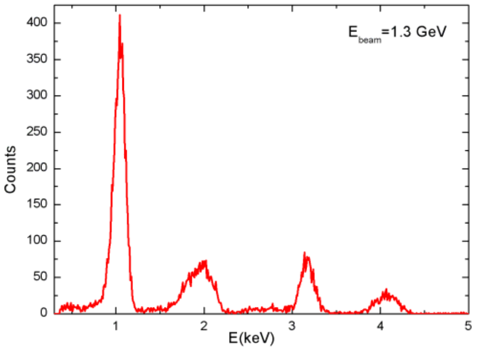

Fig. 5: Linear spectrum at 1.3 GeV (horizontal emittance ca. 10 nm) measured with a commercially available photodetector (without a monochromator). The gap width is 8 mm.

The maximum tuning speed of the undulator is 10 A per sec limited by the power supply. Due to the low inductivity of the undulator (bifilar winding technique), the full current can be reached in less than 2 minutes. The undulator installed at ANKA can operate with a maximum current of 650 A.

Fig. 6 shows how fast both the undulator and the monochromator (supplied by the University of Wuppertal [5]) can be tuned together. The tuning speed is 1 A per second. This time step allows the monochromator to follow the undulator and to perform the measurements (beam energy 2.5 GeV). The curve shows the first harmonics. A similar curve (not shown in this paper) is also available for the third harmonics.

BEAM-INDUCED HEAT LOAD

A paper presented at this conference describes the measurements of the heat load from the beam [6]. The main conclusion is that the dominant heat source is the synchrotron radiation produced in the upstream bending magnets. The heat load produced by image currents (bunch length 10 to 12 mm, 200 mA) is negligible.

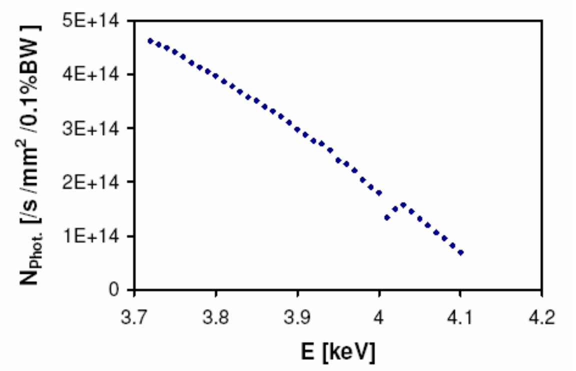

Fig. 6: Parallel tuning of the undulator current and the monochromator. The maximum tuning speed of the undulator alone is 10 A per second. The tuning speed of the undulator and the monochromator together is 1 A per second.

The heat load induced by synchrotron radiation is less than 1 Watt per 100 mA. This level makes it feasible to operate small gap superconductive undulators in ANKA without running in any problems. Nevertheless, for the use of superconductive undulators in other storage rings, it is important to understand the heat load mechanism in greater detail.

At the moment it is believed, that small vertical orbit displacements contribute to the heating mechanism. Fig. 7 shows the beam profile measured after the undulator. The round beam is produced by the undulator (with low magnetic field strength), the flat beam by the downstream bending magnet. Both beams have vertically different positions indicating that the electron beam is not on the axis of the downstream quadrupoles. Fig. 7 and fig. 2 seem to indicate hat the electron beam does not go through the center of the undulator and/or enters at an angle to the undulator axis.

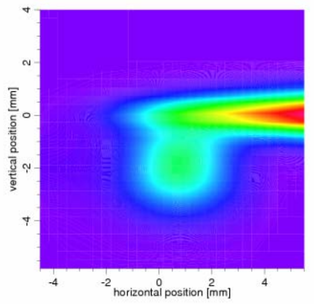

Fig. 7: The photon beam after the undulator. The round beam is the photon beam produced in the undulator, the flat beam is the photon beam produced in the bending magnet.

If there is a vertical misalignment of the beam the synchrotron radiation surrounding the beam can hit the walls of the small gap before the electron beam hits it and the lifetime is reduced. The problem is demonstrated in fig. 8. In order to prevent this happening, the next superconductive undulator will be equipped with beam position monitors and a better collimator system to stop synchrotron radiation from touching the cold bore.

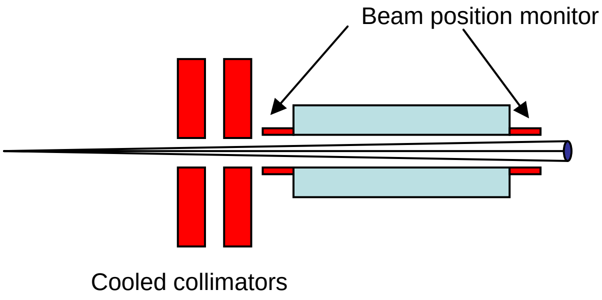

Fig. 8: The beam is vertically surrounded by a cone of synchrotron radiation with a half-opening angle of 1/γ. At ANKA this angle is 0.2 mrad. Due to the collimator the cone cannot touch the walls of the undulator when the undulator gap is well aligned. If this is not the case, part of the beam hits the cold bore.

FUTURE DEVELOPMENTS

The next superconductive undulator with a period length of 14 mm and 100 periods will be installed in about two years from now. This undulator will have a reduced phase error [7]. A superconductive undulator with an electrically variable period length and a helical undulator with electrically switchable polarization direction will follow during the next few years [8].

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