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EXPERIMENTAL RESULTS WITH A NOVEL SUPERCONDUCTIVE IN-VACUUM MINI-UNDULATOR TEST DEVICE AT THE MAINZ MICROTRON MAMI

T. Hezel, M. Homscheidt, H. O. Moser, R. Rossmanith
Forschungszentrum Karlsruhe, Project ANKA, D-76021, Karlsruhe, Germany
Th. Schneider
Forschungszentrum Karlsruhe, Inst. for Technical Physics, D-76021, Karlsruhe, Germany
H. Backe, S. Dambach, F. Hagenbuck, K.-H. Kaiser, G. Kube, W. Lauth, A. Steinhof,
Th. Walcher
Institute for Nuclear Physics, University of Mainz, Germany

Abstract

Experimental results of beam tests with a novel superconductive in-vacuum mini-undulator test device are described. The period length is 3.8 mm and the undulator is 100 periods long. The gap height can be varied between 1 and 2 mm. The tests were performed with an 855 MeV electron beam at the Mainz Microtron MAMI. The small gap undulator has been operated up to an electron beam current of 50 µA cw. The bremsstrahlung background is almost negligible and the beam does not influence the in-vacuum superconductor. In this paper the measured X-ray spectra are presented.

1 INTRODUCTION

Undulators with a short period length (less than 10 mm), a significant number of periods (100 and more) and high magnetic fields are becoming more and more interesting both for synchrotron light sources and FELs [1-5]. Those undulators need small gaps of about 1/3 to 1/4 of the period length.

In order to maintain the largest possible aperture the field generating devices of the undulators have to be placed directly in the vacuum chamber.

In this paper an undulator with a completely new approach is described. The undulator field is generated by a current through a superconducting wire. Different to other superconductive concepts [1,2] the superconducting wire is in vacuum [6]. Since the whole undulator is cooled by liquid helium the outgassing rate is very low. This is an important advantage compared to warm bore permanent magnet undulators.

2 THE UNDULATOR

Fig. 1 shows the principal layout of the undulator. The field is generated by the current through superconductive wires. The direction of current flow is opposite in two adjacent wires generating a vertical field with alternating sign along the electron trajectory. The superconducting wire is embedded into a groove. In the undulator described here the grooves are cut into soft iron. The superconducting wires are in vacuum and are indirectly cooled by liquid helium. The cross section of the wire is rectangular so that each wire can be in reality a stack of wires with identical current flow direction. In the present undulator the stack consists of four wires.

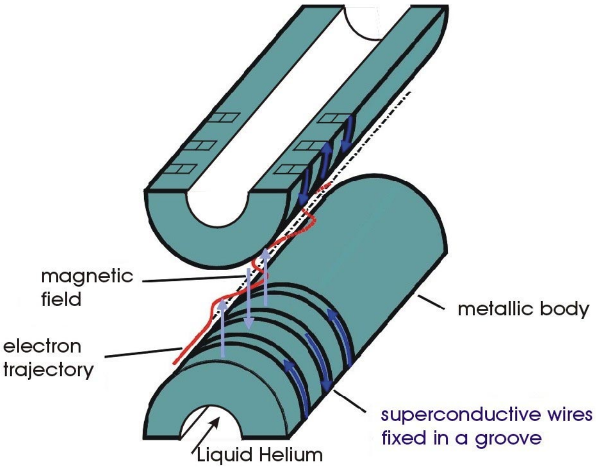

Fig. 1 Layout of the undulator. The field is generated by superconductive wires with alternating current directions. Two identical coils, indirectly cooled by LHe, are placed above and below the electron beam.

Fig. 2 shows one of the completely wound undulator coils. In the center is the tube for the liquid Helium.

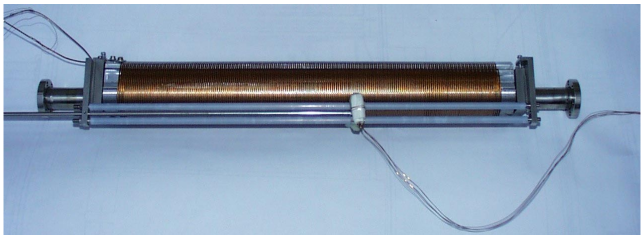

Fig. 2 One completely coiled undulator half, 38 cm long with the micro Hall probe for field measurement

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3 THE MEASURED UNDULATOR FIELD

Fig. 3 shows the measured field of one undulator coil with a miniature Hall probe (active area 100x100µm^2). The slight dipole component of the field can be compensated by optimizing the winding geometry at both ends of the coils.

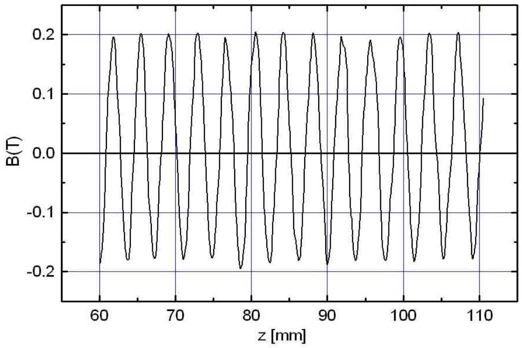

Fig. 3 Field of one undulator coil measured with a miniature Hall probe at a distance of 0.5 mm. The current was 600 A.

4 THE EXPERIMENT AT MAMI

The two undulator halfs are suspended in a vacuum vessel which is part of the normal vacuum chamber of the accelerator. Fig 4 shows the layout. The two undulator halfs are surrounded by a LHe shield. On top of the undulator is a container for LHe which provides the undulator and the shield with LHe. In order to simplify current feedthroughs the maximum current was limited to 400 A. The maximum current through the coils before quenching is 1400 A.

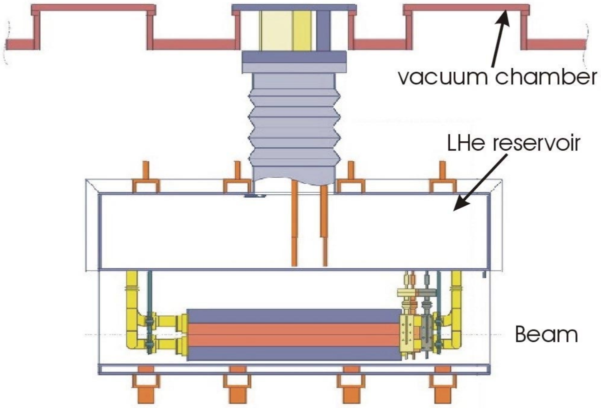

Fig. 4 The cryostat for the undulator

The measurements of the undulator radiation were performed with an 855 MeV beam at the Mainz microtron MAMI at a beam current up to 50µA cw. The undulator is followed by a bending magnet which separates the electron and the X-ray beam (fig. 5). 12 m downstream of the undulator is a Ge detector with a 200 µm wide pinhole which can be moved perpendicularly to the beam. With this arrangement it is possible to measure the spatially resolved spectrum.

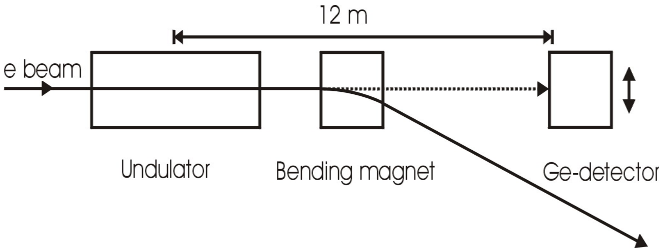

Fig. 5 Schematics of the experimental setup.

The measured spectrum on the undulator axis is shown in fig. 6. The current of MAMI was reduced so that the detector measured single photons (current of about 30 pA). The peak energy of the spectrum is close to the expected value. The FWHM is mainly determined by the detector resolution of 150 eV. The low energy tail stems from the curvature of the beam path due to the residual dipole field. As a result of the curvature of the horizontal beam path photons emitted under a larger angle and therefore lower energy can hit the detector.

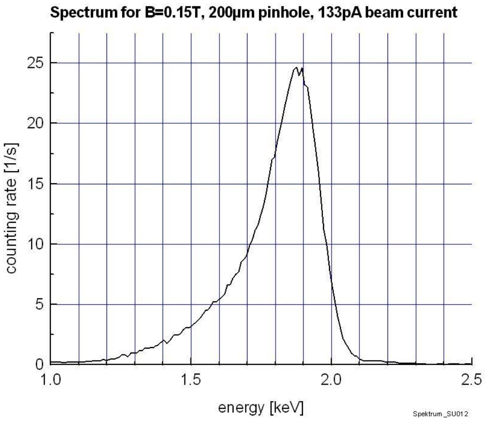

Fig. 6 The measured spectrum. The detector resolution is ca. 150 eV.

The complete spatially resolved spectrum (again measured with a Ge detector and a 200µm pinhole) is shown in fig. 7. The pinhole-detector ensemble can be moved together perpendicularly to the beam direction. The measurements were performed at a distance of 12 m from the undulator. The data are in excellent agreement with the fundamental formula of the photon energy of an undulator

$$E_{Phot} = \frac{2hc\gamma^2}{\lambda_u}\frac{1}{1+\frac{K^2}{2}+\gamma^2\left(\frac{x}{d}\right)^2}$$

where, in the present case, λ_u is 0.38 cm, the period length of the undulator, K is the undulator parameter

$$K = 0.934\ B_{max}\ [T]\ \lambda_u\ [cm]$$

B_{max} the maximum field in Tesla, d the distance between the undulator and the detector and x the vertical position of the detector (Fig. 8).

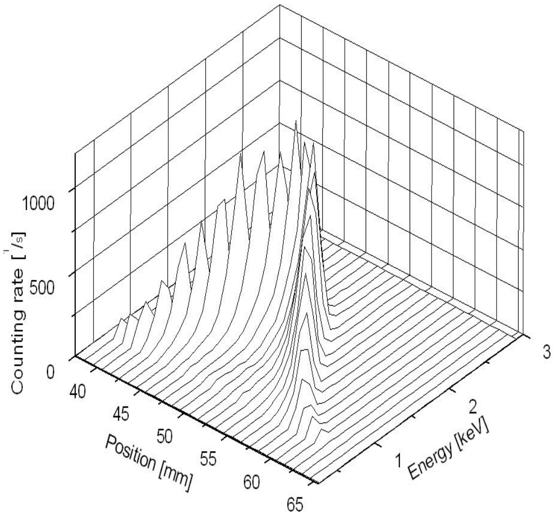

Fig. 7 Vertical spatially resolved X-ray undulator spectrum with a 200 µm pinhole and a Ge detector at a distance of 12 m from the undulator.

Due to the curvature of the horizontal trajectory which is caused by the dipole component the horizontal spectrum is, as expected, smeared out.

5 PLANNED FUTURE EXPERIMENTS AND IMPROVEMENTS

In summary it was shown experimentally that a superconductive undulator with a period length of several mm works perfectly with a beam. In a next step the dipole field of the undulator will be compensated. This can be achieved by shaping the grooves at the end of the coils and by additional trim coils.

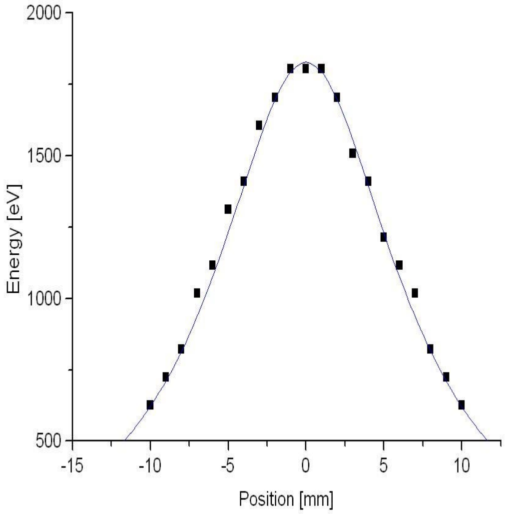

Fig. 8 Peak energy values (rectangles) compared with the undulator formula given above (solid line).

One natural application of the undulator will be in the field of X-ray and VUV FELs. The short period length allows to reach the VUV and X-ray region with relatively modest beam energies (1 to 2 GeV). Studies for a test are under way.

Finally a test with a high current beam in a storage ring is considered for the near future. In this test an undulator is envisaged which allows to tune the radiated light over a wide range purely electrically. This requires a period length in excess of 1 cm to reach K values of about 2 and allows, as a consequence, larger gaps of about 5 mm.

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