DESIGN, DEVELOPMENT AND TESTING OF DIAGNOSTIC SYSTEMS FOR SUPERCONDUCTING UNDULATORS*

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Abstract

Within the framework of a joint research activity of the European integrated infrastructure initiative "Integrating Activity on Synchrotron and Free Electron Laser Science" four synchrotron facilities have jointly developed diagnostic systems for superconducting undulators. Four work packages have been successfully completed: Design and construction of a test cryostat for field measurements; design and construction of a mock-up coil; field measurement and field error compensation; diagnostics and measurement of the spectrum of low energy electrons responsible for beam heat load in a superconducting undulator. The development advanced the knowledge of magnetic field error compensation considerably and might be of help in understanding the different beam heat load sources. Based on the development a second generation planar superconducting undulator with 15 mm period length for the synchrotron light source ANKA has been specified and procured.

INTRODUCTION

In order to produce synchrotron radiation of highest brilliance, third generation synchrotron sources make use of insertion devices, or more specifically undulators. The radiation spectrum produced by the multiple wiggles that the particle beam experiences is, contrary to bending magnet radiation, sharply peaked at specific photon energies. At these photon energies the radiation generated by the particle beam on its path through the undulator interferes constructively, giving rise to an increase in brilliance proportional to the square of the number of periods of the undulator. Together with the fundamental spectral line an undulator produces a family of higher harmonics. The emission of the undulator in the X-ray range can either be achieved by a high energy of the particle beam or a very short period length of the undulator. The X-ray wavelength λ of the fundamental is proportional to the undulator period length λ_u divided by $2\gamma^2$, with γ the energy of the particle beam [see 1]. A medium particle beam energy of storage ring light sources will require a significantly shorter undulator period length in order to generate the same X-ray wavelength.

The best magnet technology available for short period undulators today is the permanent magnet technology with magnet blocks placed in the vacuum of the storage ring. Following an initial proposal at SPRING8 [2], the concept of Cryogenic Permanent Magnet Undulators (CPMU) is presently considered as a possible future evolution of in vacuum undulators [3 - 6]. Superconducting undulators can reach by the same gap and period length higher fields even with respect to CPMU devices. All four long straight sections of the ANKA storage ring are planned to be equipped with superconducting insertion devices. Superconducting undulators are considered for future storage ring medium beam energy light sources [7] or linac light sources [8, 9]. The joint research activity JRA4 of IA-SFS targeted the design, development and testing of superconductive technology for undulators. The initially defined development of a full short period superconducting undulator to be installed and tested on the European Synchrotron Radiation Facility has been found to need more R&D than expected and became incompatible with the IA-SFS time duration and a revised goal has been defined to experimentally verify two important subsystems of superconducting undulators: correction of phase errors of the periodic magnetic field and optimisation of the cryo-technology. Four European facilities, ANKA, ESRF, Elettra and MAX-lab have joined forces to prove the application of such systems. The project partners exploit their specific expertise [10, 11] also based on the experience gained with the superconducting demonstration undulator operational at the synchrotron radiation source ANKA.

ACHIEVEMENTS

The optimisation of superconducting technology within JRA4 focuses on two major issues, the quality of the magnetic field of long undulators and the heat load to cold bore devices. Significant advances have been achieved in the measurement and correction of magnetic field errors. The heating of cold bore devices due to bombardment of low energy electrons in the vacuum pipe has been studied both theoretically and experimentally.

*Work supported by the European Commission under contract RII3-CT2004-506008
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Magnetic Field Measurement and Field Error Compensation

The goal of three work packages is to study the magnetic field quality and its influence on the device performance including the possibility of introducing local field correction coils, so-called shimming. As the field quality is critical for the coherence condition of synchrotron light generated by an undulator, shimming is needed to optimize the magnetic field along the undulator axis. In superconductive undulators, phase errors are caused by mechanical deviations of the pole position, the pole height and the position of the superconducting coils.
Two types of shimming concepts have been evaluated: active and passive. Active shimming consists in adding an additional layer of superconducting wire on top of the main coils in order to provide a field perturbation that can correct the field errors. The shimming concept has been developed [12]. To compensate for the error in the coils additional solenoid-like windings on the top of the main coils can be added and for the pole error a racetrack coil is applied. The maximum correction field for the two geometries has been measured in the vertical liquid helium bath facility CASPER I at FZK as shown in Fig. 1 [13].

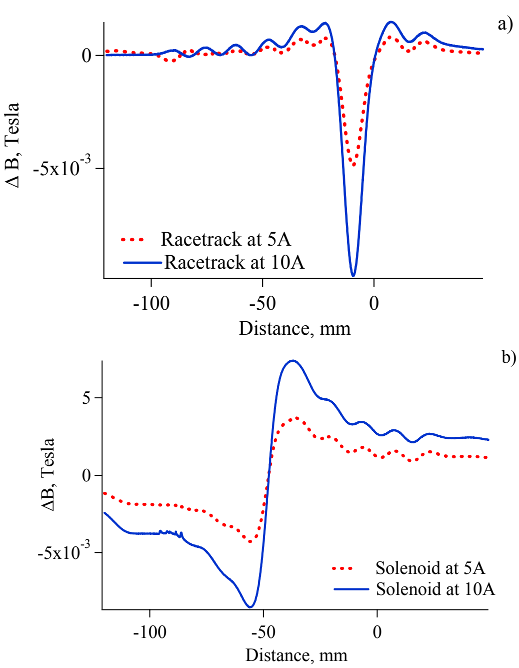

Figure 1: Efficiency of the racetrack (above) and solenoid (below) field at two different currents on the background field of the main coil powered with 50 A current.

The correction field of the racetrack geometry is very localized and amounted to a few percent with respect to the main field. The solenoid correction field is lower in amplitude and extends over a few periods.

The passive field compensation called induction-shimming has been experimentally demonstrated [14]. In this scheme the deviations from an ideal magnetic field of the main superconducting coils are compensated by a set of overlapping correction loops of a type-II superconductor.

Optimisation of the Cryo-technology

One of the key issues for the development of superconducting insertion devices is the understanding of the beam heat load to the cold vacuum chamber. A work package of the joint research activity JRA4 is implemented to advance our knowledge in this field.

Possible beam heat load sources of superconducting undulators are:

- synchrotron radiation
- resistive wall heating
- electron and/or ion bombardment
- RF effects

The values of the beam heat load due to synchrotron radiation and resistive wall heating have been calculated and compared for the different cold vacuum chambers with the measured values. The difference between beam heat load measured and calculated is not yet understood. Studies performed with the cold bore superconducting undulator installed at the synchrotron radiation source ANKA investigated the possibility if the higher beam heat load comes from electron bombardment [15]. As a result of the electron bombardment the beam heat load increases and the dynamic pressure rises as observed for bunch lengths of about 10 mm. In this model low energy electrons (few eV) are accelerated by the electric field of the beam to the wall of the vacuum chamber, induce non-thermal outgassing from the cryogenic surface and heat the undulator. The existence of low energy electrons outside the undulator (see Fig. 2) has been verified using a retarding field analyser [16].

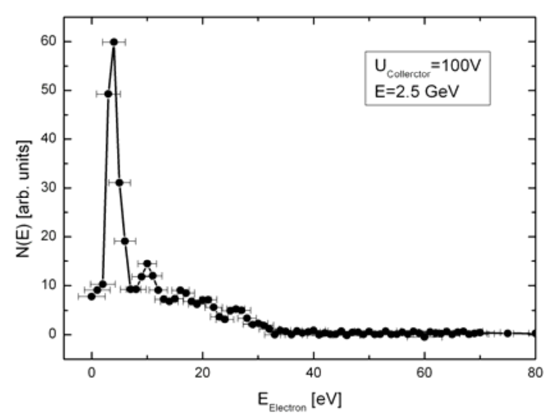

Figure 2: Spectrum of the energy of low energy electrons inside the vacuum system of the ANKA storage ring at a beam energy of 2.5 GeV.

In order to gain a quantitative understanding of the problem and find effective remedies we plan to build a cold vacuum chamber for diagnostics [17]. The goal is to measure the heat load, the pressure, the gas content and the flux and spectrum of the low energy electrons bombarding the wall. A special electron energy analyser has been developed and tested in synchrotron accelerator. Resulting from the activities, a dedicated instrument for the measurement of beam heat load in a cold bore device installed in accelerators called COLDDIAG (COLD vacuum chamber for DIAGnostics) will be constructed. An experiment is envisaged at the third generation synchrotron facility Diamond light source. The COLDDIAG results are expected to be of interest for high energy physics accelerators as the Large Hadron Collider LHC and future international linear colliders ILC or CLIC.

IMPACT

Based on the development conducted under JRA4 Forschungszentrum Karlsruhe has decided to procure the superconducting undulator SCU15. The undulator is currently under construction at the company Babcock Noell GmbH. The active type shimming developed in JRA4 has been selected for the correction of field errors of the SCU15 superconducting undulator. It was implemented by Babcock Noell GmbH.

The research will influence and advance novel accelerator technology beyond synchrotron radiation sources. The extraordinary characteristics of superconducting undulators are expected to be exploited for ring-based third generation synchrotron radiation sources, free-electron lasers, emittance damping rings for future linear accelerators, and table-top free-electron lasers.

ACKNOWLEDGEMENTS

Major supporting activities conducted by M. Commisso and R. Cimino at Laboratori Nazionali di Frascati (LNF, INFN), Italy, are gratefully acknowledged.

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