FIRST TESTS WITH A LOCAL AND INTEGRAL MAGNETIC FIELD MEASUREMENT SETUP FOR CONDUCTION COOLED SUPERCONDUCTING UNDULATOR COILS

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Abstract

During the last years improvements in magnetic field measurement technology of conventional, i.e. permanent magnet based insertion devices (IDs), made significant progress and pushed the capabilities of synchrotron light sources. For superconducting IDs similar developments are now needed to perform precise measurements of local magnetic fields and field integrals. We follow this aim within our R&D program for superconducting IDs.

This contribution describes challenges of the design and measurement setup to perform magnetic measurements of the local field and of the field integrals of superconducting undulator coils in a cold, in-vacuum (cryogen free) environment together with results of first tests.

INTRODUCTION

In synchrotrons, undulators are used as sources for high brilliance X-ray beams [1]. The phase error and the field integrals are the important figures of merit of an undulator. Ideally the field integrals along the beam axis should be zero, so that there is no effect on the electron beam orbit. The quality of the emitted radiation is related to the phase error. The phase and the wavelength are determined by the period length, field strength and the beam energy. If one of these parameters deviates in one or several periods the photons emitted by an electron at the undulator poles are not in phase. As a consequence, the flux on axis at the harmonics is reduced.

At the synchrotron ANKA (ANgströmquelle KArlsruhe), situated at the Karlsruhe Institute of Technology (KIT), there is an ongoing R&D program established to develop superconducting IDs [1].

To measure field errors of short superconducting undulator test devices with a maximum length of 350 mm and a maximum diameter of 300 mm at 4.2 K a cryostat setup called CASPER I (ChAracterization Setup for Phase Error Reduction) was built in 2007, and is in operation [2].

To develop, built and optimize feasible devices with a small field error for synchrotron radiation sources of 3rd and 4th generation, it is mandatory to measure the local field distribution and the field integrals of long coils ranging from 1 to 2 m. For measuring these quantities an easily accessible cryostat, CASPER II, for coils up to 2 m long was built by the company CryoVac (Troisdorf, Germany) and delivered to the KIT in July 2011.

Here we describe the final measurement setup of CASPER II together with first tests performed with a short conduction cooled mock-up coil.

CRYOSTAT

In superconducting IDs the coils are usually aligned horizontally and conduction cooled via cryocoolers thermally connected, or immersed in a liquid helium bath. To perform tests in a similar arrangement as in final IDs with conduction cooling using cryocoolers, the inner part of the cryostat is in vacuum. The absence of liquid helium offers flexibility to apply various measuring techniques.

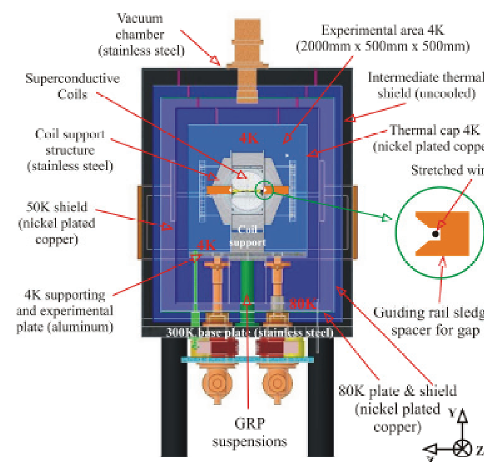

Figure 1: Sectional view along z-axis of CASPER II showing the different temperature shields.

Figure 1 shows a cross section of the cryostat vacuum chamber, where one can see its shell-like structure to facilitate the exchange of the coils.

Two different field measurement techniques will be used: Hall sensors for local field measurements and the stretched wire method for measuring the field integrals. The coils are mounted in a stiff stainless steel support structure (Fig. 1, 2) which takes the force resulting from the magnetic field, and are arranged horizontally as in the final ID.

An advantage of the described setup is that the local field and field integrals can be measured in the same arrangement. First an x-y-positioning system with encoders places the wire at rest in the corner of the spacer (Fig. 1); then local field measurements can be performed. After these measurements, the sledge can be pulled to its

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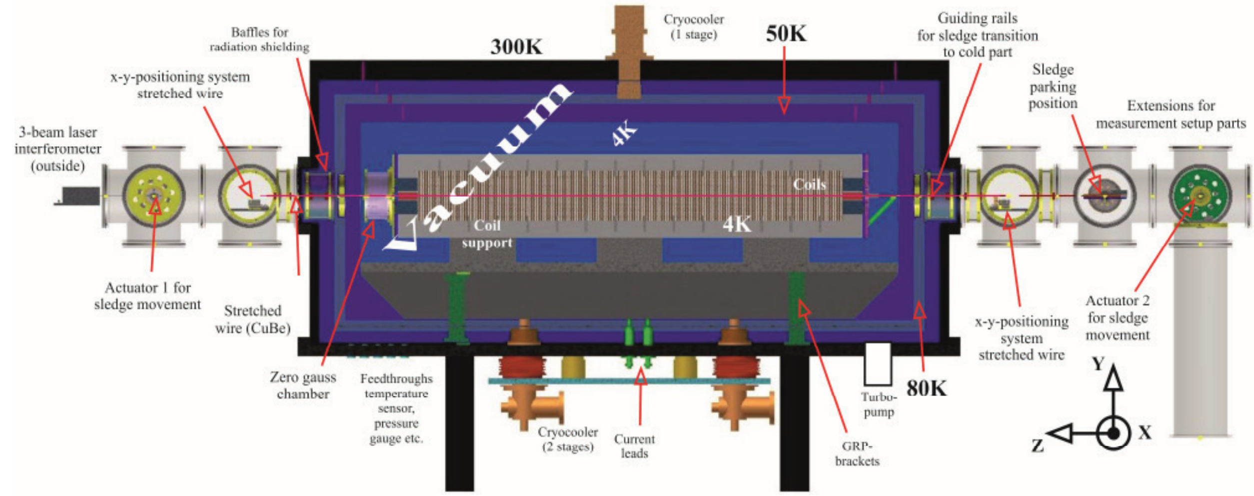

Figure 2: Side view of the cryostat CASPER II showing the equipment for local and integral field measurements.

rest position in the outside area, shown in Fig. 2, to measure the field integrals with the stretched wire.

A big challenge is to measure with a stretched wire and Hall samples in the same setup and without a thermal cycle. Therefore, additionally to the coils, also the measurement setups have to be installed and constructed to be used in vacuum. This is solved by extending the vacuum with sealed pumping crosses on each side of the cryostat where the measurement setup parts are mounted (Fig. 2).

Hall sample measurement setup

To measure the local field distribution of the coils three Hall sensors are placed on a brass sledge, which will be pulled through the gap along the undulator coils (Fig. 2). To measure the position of the Hall sensors, a laser interferometer will be mounted outside the cold part, at the extensions that are foreseen on each side of the cryostat (Fig. 2).

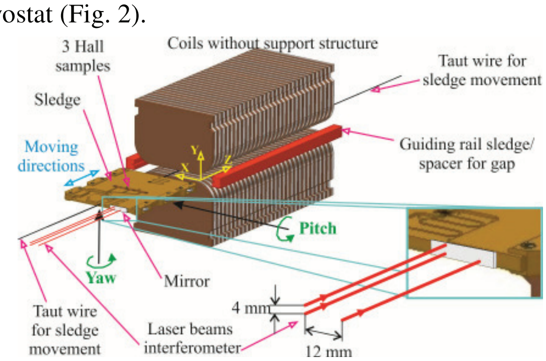

Figure 3: Drawing of the coils with the sledge for local field measurements. The coil support structure is not shown.

The interferometer is a SIOS SP-2000-TR triple beam laser interferometer and the beams are reflected by a mirror on the Hall sensor sledge, as shown in Fig. 3.

To point onto the mirror in the gap between the undulator coils, the distance of the interferometer beams in vertical direction had to be reduced from the commercially provided 12 mm. This is achieved by a pair of mirrors attached just at the interferometer beam exit of the uppermost beam. The mirrors perform two times a 90° deflection resulting in a vertical beam distance of 4 mm (Fig. 3).

With this arrangement the precise position of the sledge and of the Hall samples along the moving direction can be measured within 1 μm. By using measurement data from all three beams, it is additionally possible to calculate the values of the angles of rotation (pitch and yaw) of the sledge during movement.

The interferometer specifications state an angular resolution of 0.02 arcsec with 12 mm beam distance. Due to the beam distance reduction, the angular resolution will be reduced by a factor of 3 to 0.06 arcsec.

To measure field components which are non-perpendicular to the x-z-plane, it is foreseen in a second phase, to manufacture a sledge where an array of Hall samples is build in as shown in Fig. 4.

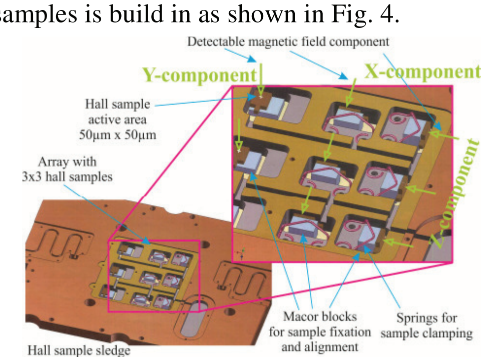

Figure 4: Sketch of the sledge with 3x3 Hall sample array.

The Hall samples are fixed to precise machined macor blocks. This combination will then be orientated under the microscope to align the measuring areas perpendicular to each other. In addition the active areas need to be placed in the horizontal plane (x-z-plane) defined by the middle of the gap, in-line along the moving direction, as well as perpendicular to the moving direction.

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Stretched wire measurement setup

It is important to achieve small field integrals to keep the undulator transparent for the electron beam. A common technique to measure field integrals is the stretched wire method: a thin wire stretched along the ID is moved in the gap of the undulator perpendicular to the main beam direction. The voltage induced by the movement of the wire is proportional to the field integrals values.

We will use a Copper-Beryllium (CuBe) wire with 125 µm diameter. For movement it will be fixed to x-y piezo stages in the extensions on both sides of the cryostat (Fig. 2), which can move synchronous ± 65 mm in x-direction and ± 20 mm in y-direction. Before taking measurement data, the piezo stages will be moved to limit switches to ensure that the wire is aligned to the longitudinal axis of the coils and that there is no contact between the wire and the guiding rails. The measurement signal will be taken from voltage taps outside in the warm part, near the first deflection roll, by a Keithley nanovoltmeter.

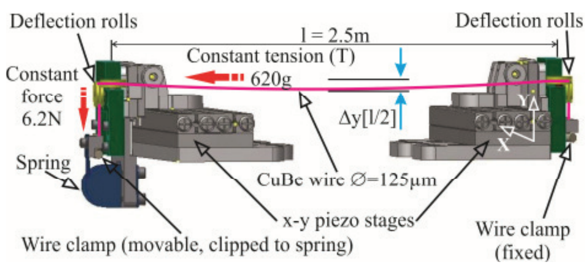

Figure 5: Stretched wire setup.

The tension to keep the wire straight will be applied by a 6.2 N constant force spring fixed to one stage (Fig. 5).

For this measurement technique the main error is the positioning of the wire due its weight. The wire bends along the longitudinal direction, and has the typical shape of a hanging chain [3]. With this approximation, a wire sag of Δy = *-82* µm is achieved in the middle of the measurement device, at $z = l/2$ and $l = 2.5$ m .

To check this result a setup with a distance $l = 2$ m of the piezo stages and $T = 620$ g was built on a precise granite measuring table. The vertical distance between the CuBe wire and the table surface at both ends and in the middle of the wire was measured with gauge blocks, resulting in a sag of $\Delta y = 50$ µm. This is in very good agreement with $\Delta y = 52$ µm which can be calculated from [3]:

$$\Delta y\left(\frac{l}{2}\right) \cong -\frac{\omega_{CuBe}\ l^2}{8\,T} = -52\ \mu m\,,$$

with $l = 2$ m and $\omega_{CuBe} = 64$ mg/m. Where ω_{CuBe} is the mass per unit meter of the CuBe wire, l is the length between the supporting points of the piezo stages, and T is the applied tension on the wire (see Fig. 5).

MOCK-UP QUENCH TESTS

In the new superconducting undulator (SCU) demonstrator which is to be tested at ANKA and is in the final acceptance state at the manufacturing company Babcock Noell GmbH (BNG) the coils will be conduction cooled by cryocoolers [4]. To confirm the cooling concept we performed quench tests on a 10-plate mock-up coil resembling the final SCU demonstrator coils.

The cooling was performed as during the final acceptance test and we took data from temperature sensors along the cooling line. The time to cool down decreased to ~ 70 h because of an improved copper braid connection from the cold head to the coil (560 mm² cross section). At the cold head a final temperature of 3.4 K was reached and a gradient of 0.2 K along the cooling connection to the coil, which was at 3.6 K, was achieved.

The temperatures at the cold head and the coil are reported as a function of time for several quenches in Fig. 6 (inset). After few quenches 200 A were reached, and one can see how the temperature difference between the cold head and the coil changes from 0.2 K before, to 9 K at quench.

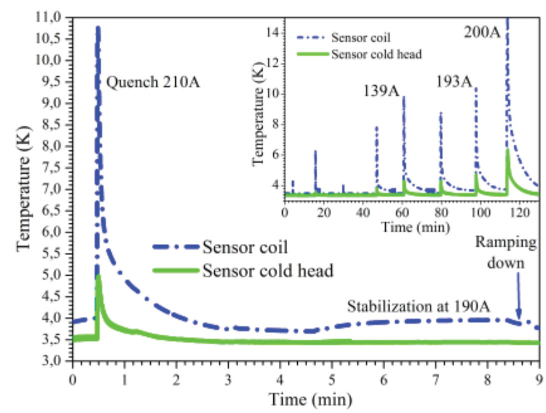

Figure 6: Temperatures over time during quench tests.

The latest quench happened at a current of 210 A which is 12 % less than the values reached during previous tests in liquid helium. This quench was most probably caused by superconductor warming based on joints inserted in the winding packages.

From Fig. 6 one can see that this heat intake can be cooled to stabilization at 4 K up to a current of 190 A which is well above the operation current of 155 A foreseen for the new ANKA SCU demonstrator.

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