DEVELOPMENT OF INSTRUMENTATION FOR MAGNETIC FIELD MEASUREMENTS OF 2M LONG SUPERCONDUCTING UNDULATOR COILS

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Abstract

Precise measurements of the magnetic properties of conventional, i.e., permanent magnet based insertion devices has undergone tremendous improvements over the past 10 to 15 years and initiated a new era in synchrotron light sources worldwide. A similar breakthrough is now necessary in the field of superconducting insertion devices.

In this contribution we describe the planned instrumentation to perform magnetic measurements of the local field, the field integrals of superconducting undulator coils up to 2m length in a cold in vacuum (helium free) environment.

INTRODUCTION

Undulators are used in third generation light sources to produce high brilliance photon beams. The photons emitted along the electron sinusoidal trajectory interfere constructively if the phase advance between successive poles is equal to π. The phase advance 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 cannot interfere constructively. Together with the phase error, important figures of merit for an undulator are the field integrals, which should be zero along the beam axis so that there is no effect on the electron beam orbit.

Superconductive undulators (SCUs) can achieve for a given gap and period length higher fields with respect to permanent magnet undulators.

At ANKA we have an ongoing research and development program to develop superconducting insertion devices. Of high relevance for our R&D program are the tools that we have developed and that are under development to improve and perform quality management of the magnetic field properties of such devices.

The device CASPER (**C**h**A**racterization **S**etu**P** for field **E**rror **R**eduction) was built in 2007 at the Institute for Synchrotron Radiation/Ångströmquelle Karlsruhe (ISS/ANKA) at the Karlsruhe Institute of Technology (KIT) [1]. This is an operating facility where we can test on small mock-ups (max. length 350 mm, max. diameter 300mm) winding schemes, superconducting materials and wires, and field correction techniques. The mock-ups are tested in a liquid helium bath. In this contribution we describe CASPER II [2], a device to qualify the magnetic field properties of coils up to 2m long, focusing on the setup and instrumentation for local and integral field measurements.

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CRYOSTAT DESIGN

The cryostat is build by the company CryoVac (Troisdorf, Germany) and will be delivered to KIT in summer 2010. The inner part of the cryostat is in vacuum, to be as flexible as possible for using various measuring techniques. For local field measurements Hall sensors mounted on a sledge pulled through the gap of the undulator on guiding rails will be used. The stretched wire technique is foreseen to measure field integrals.

As shown in fig. 1 the cryostat has a shell-like structure to facilitate the exchange of the coils. The cryostat consists of 3 plates at 300K, 80K and 4K, with respective shields.

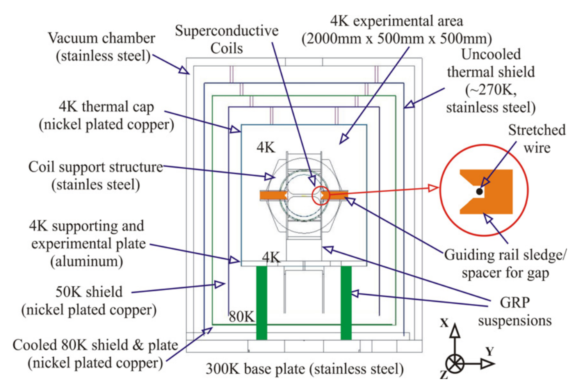

Figure 1: Drawing of the cryostat´s different temperature regions and the experimental chamber with the entry for local and integral field measurement systems.

Cooling to 80K at the second plate and pre-cooling the 4K plate will be done with liquid nitrogen flowing through heat exchangers (fig. 2). To reach the final 4K on that plate four 2-stage cryocoolers are foreseen. They are connected to the plate and the coils in parallel to keep their temperature stable. To power the main coils and/or additional correction coils 8 current leads with 500A each are foreseen. For reducing the thermal heat load on the 80K shell caused by radiation, there is one uncooled shield fixed with GRP (glass reinforced plastic) suspensions at the outer stainless steel vacuum chamber.

This cover reduces the thermal load on the 80K shield due to its almost perfect finished surface and resulting good emissivity. The temperature of this shield will be 270K.

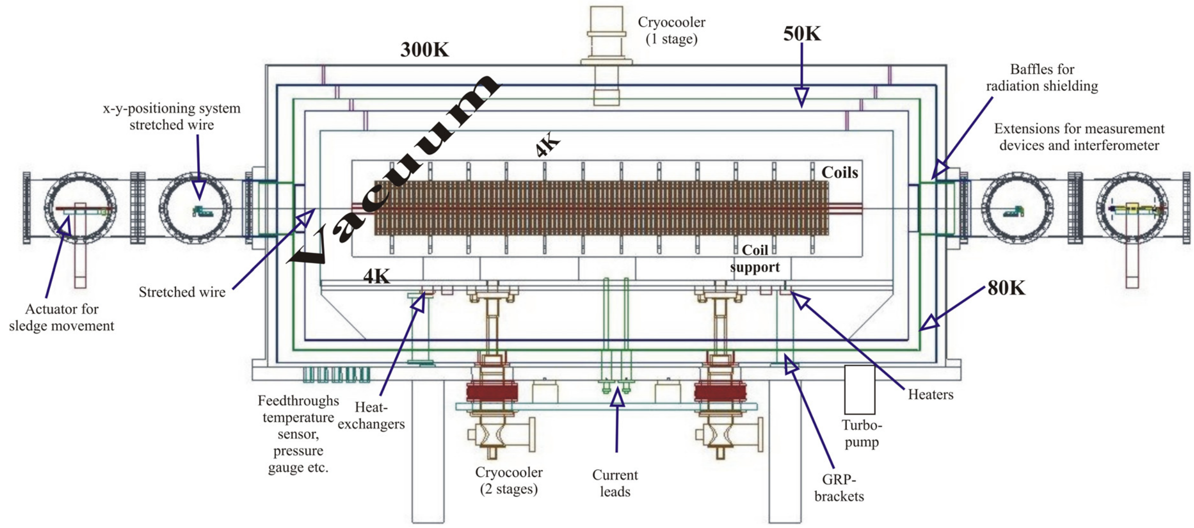

Figure 2: Side view of the cryostat (CASPER II) with the equipment for local and integral field measurements.

To take the heat load on the 80K cover a 1-stage cryocooler will be used (fig. 2).

Between the 80K cover and the 4K region there is another intermediate shield at 50K which is cooled by the 1st stage of one of the 2 stage cryocoolers. The 1st stages of the others take away the conduction heat load of the 8 current leads (8x500A, fig. 2).

Two different field measurement techniques will be used: Hall sensors for local field measurements and the stretched wire method for measuring the field integral. To measure the position of the sensors a laser interferometer will be mounted outside the cold part in the extensions that are foreseen on each side of the cryostat and where also the measurement setups are installed (see fig. 2). The laser is reflected by a mirror on the Hall sensor sledge and will allow us to measure the relative longitudinal position with a precision of 1µm.

LOCAL FIELD MEASUREMENTS

In order to perform measurements in a setup as close as possible to the arrangement of the coils in the final undulator cryostat, the gap is aligned horizontally in the cryostat. The coils are mounted in a stiff support structure to take the force resulting from the magnetic field.

For local field measurements we place 3 Hall sensors with a distance of 20mm between each in x-direction on a brass sledge of 150mm length and 130mm width. The sledge will be pulled through the gap along the undulator. On each side of the sledge a wire is attached to enforce the movement in both directions by two stepper motors located on both sides of the cryostat. They work synchronous and coil the wire on a bobbin. The precise position of the sledge and hence the Hall samples is measured by the laser interferometer. This allows a precise field mapping of the local field. To measure always in the gap middle the sledge is guided by a sliding rail (fig. 1, 3).

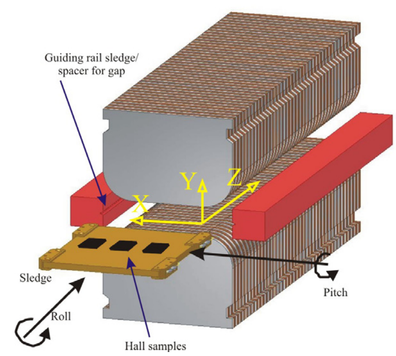

Figure 3: Sketch of the coils with the setup for local field measurements.

Accuracy Specifications

The mechanical tolerances of the setup are crucial for the field measurements. With our setup we want to be able to measure a phase error of $\Delta\Phi = 1°$ for an undulator similar to the one under construction for ANKA (SCU15) [3], with the following parameters: 15mm period length, gap g=8mm, B=0.78 T and K=1.1.

According to [4, 2] this means for the resolution in the magnetic field $\frac{\Delta B}{B}$:

$$\frac{\Delta B}{B} = \frac{\Delta\Phi}{360°} * \frac{\left(1 + \frac{1}{2}K^2\right)}{K^2} = 0.0035\,. \qquad (1)$$

In x-direction the field is fairly uniform, therefore the deviations are uncritical and we focus on the allowed deviations of the Hall probe in y-direction (across the gap) and z-direction (along the undulator). The field in a undulator is given by [4]

$$B_y(y,z) = B_0 \cosh\left(\frac{2\pi \cdot y}{\lambda_U}\right)\sin\left(\frac{2\pi \cdot z}{\lambda_U}\right) \qquad (2)$$

where B_0 is the peak field and λ_U is the period length. To calculate the maximum error in y-direction one considers the change in $\frac{\Delta B}{B}$ from above. This occurs when

$$\cosh\left(\frac{2\pi\Delta y}{\lambda_U}\right) = 1.0035\,. \qquad (3)$$

For λ_U = 0.015m the result is Δy = 200µm. The relative alignment of the guiding rails is 20µm and for the Hall sample in the middle of the sledge the distance to the coils can only change by 10µm. So we are far below the limit.

As an estimation for the maximum allowed deviation in z-direction one can calculate the change of the trajectory slope due to an axial error in the probe position (Δz). Following [4] we use

$$\Delta z = \frac{\gamma\, m_e\, c}{2\, e} \cdot B_0 \cdot x' \qquad (4)$$

being m_e the electron mass, c the speed of light, e the charge of the electron, γ the Lorentz factor, B_0 the peak field and x' the electron kick proportional to the first field integral. With the slope x' calculated from the specified first field integral for the SCU15 for ANKA (I_1 = 20µTm), the Lorentz factor γ =5000 and B_0 =.78T the result is Δz =10µm. Due to the fact that we measure the sledge position with a laser interferometer we reach a precision in z-direction in the sub micrometer region.

In addition errors like roll and pitch might have to be taken into account. However as one can see if we take (3) and insert a maximum mechanical deviation of the Hall sample from the middle of the gap (Δy =10µm) the result for the error caused by the roll of the sledge is $\frac{\Delta B}{B} = 8.8 \cdot 10^{-6}$. The same holds for the pitch: is very small and can be neglected in our case.

FIELD INTEGRAL MEASUREMENTS

The first and second field integral are proportional to the angular and position change of the electron beam at the undulator exit. It is important to keep the field integrals as small as possible to keep the undulator transparent for the electron beam.

To measure the field integrals we will make use of the stretched wire technique: a thin wire stretched along the ID is moved in the gap of the undulator perpendicular to the main beam motion. From the resulting induced voltage during the movement of the wire one obtains the field integrals values.

One advantage of the described setup is that the local field and field integrals can be measured in the same arrangement. First a x-y-positioning system with encoders places the wire (Copper Beryllium, CuBe 100µm diameter) at rest in the corner of the spacer (fig. 1 and 4). Then, local field measurements can be performed. After, the sledge can be pulled to its rest position in the outside area shown in fig. 3. The encoders have a resolution of 1µm for a moving length of 130mm in y-direction and ± 20mm in x-direction, with the possibility to obtain higher order multipole components. The distance between the two moving units is 2.5m (fig. 4). Both can be moved synchronous in the same or opposite direction on both axis.

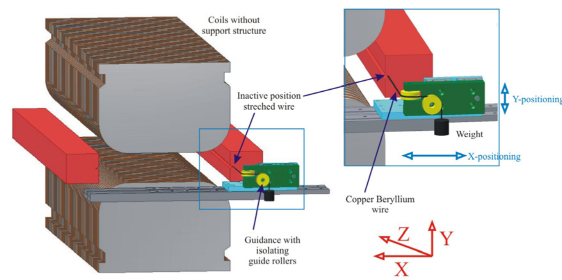

Figure 4: Drawing of the coils with stretched wire components

A tension (T) will be applied by a weight of 200g and keep the wire straight for l=2.5m. This implies the following sag in the middle $\left(\frac{l}{2}\right)$ of the measuring device

$$\Delta y\left(\frac{l}{2}\right) \cong -\frac{\omega_{CuBe}\, l^2}{8T} = \text{- } 250\mu\text{m} \qquad (5)$$

with the mass density per unit meter (ω) for CuBe of 64mg/m [5]. Following [6] the error for the first field integral caused by the sag Δy is

$$\frac{\Delta I_y}{I_y} \approx \left(\frac{2\pi}{\lambda_U}\right)^2 \cosh\left(\frac{2\pi}{\lambda_U}\Delta y\right) \cdot \frac{\Delta y^2}{2} \approx 5 \times 10^{-3}.$$

CONCLUSION

In order to perform quality certification of magnetic field properties for long superconducting undulator coils a horizontal, helium free, in vacuum measurement setup for local field mapping and field integral analysis is currently build.

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