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CRYOGENIC, IN-VACUUM MAGNETIC MEASUREMENT SETUP FOR SUPERCONDUCTING UNDULATORS

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Abstract

The magnetic field quality has a strong impact on the performance of insertion devices (IDs) when installed in synchrotron light sources. Superconducting IDs have the advantage to produce a higher magnetic peak field for a given vacuum gap and period length than IDs assembled with permanent magnets. Before installation of a superconducting ID in a synchrotron light source it is of fundamental importance to characterize the magnetic properties by accurate field and field integral measurements. We follow this aim within our R&D program for superconducting undulators (SCUs).

In this contribution, we describe the equipment and the challenges of a cryogenic, in-vacuum measurement setup to perform magnetic measurements of the local field, the field integrals and the multipole components of SCUs assembled in the final cryostat.

INTRODUCTION

The technology of insertion devices (IDs) is widely used in state-of-the-art synchrotron radiation sources to produce high brilliant photon beams for numerous applications [1]. Competing technologies to generate the periodically alternating magnetic field distribution are arrangements of permanent magnet blocks, or iron yokes wound with superconducting wires. For a given vacuum gap and period length, the superconducting technology allows to increase the flux and brilliance with respect permanent magnet technology.

At the Institute for Beam Physics and Technology (IBPT) at the Karlsruhe Institute of Technology (KIT) there is a well-established long-term R&D program ongoing to develop superconducting insertion devices together with the industrial partner Bilfinger Noell GmbH (BNG) [2]. After the successful test of a full-scale superconducting undulator with 15 mm period length (SCU15) in the KIT synchrotron [3], a new full-scale device with 20 mm period length (SCU20) has been installed in December 2017 [4]. Before installation in the final cryostat, the superconducting coils of SCU20 were tested in terms of electrical performance and magnetic field characterization in the horizontal, cryogen-free magnetic field measurement setup CASPER II at the IBPT at KIT [5]. A further step forward in the qualification of superconducting IDs is the magnetic field characterization of the coils in the final ID cryostat.

In this contribution, we describe a new, in-vacuum, cryogenic magnetic measurement setup to perform magnetic qualification of SCUs in the final cryostat.

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MEASUREMENT SETUP

After testing of superconducting coils in laboratory conditions, they are mounted in the final cryostat, which later is installed in a synchrotron radiation source. Typically, the cryostat of a superconducting ID such as a SCU has a shell-like structure consisting of an outer isolation vacuum vessel at room temperature, intermediate temperature shields at ~50-70 K and below 10 K, to thermally screen the coils (Fig. 1). The ultra-high vacuum (UHV) of the electron beam is separated from the isolation vacuum, where the coils are placed, by a so-called liner, made for the KIT-BNG SCUs out of a 300 µm thin stainless-steel foil. Since the new measurement setup will be attached to the UHV chamber of the SCU, and will have the possibility to be adapted to different IDs, all measurement components are designed for UHV environment.

Based on the operating experiences with the CASPER II system, three techniques to measure the magnetic properties of a SCU will be combined in the new setup:

- Local field mapping along the magnetic axis by a Hall sensor, which can be used for vacuum gaps > 5 mm.
- A stretched wire to perform a fast measurement of the longitudinal field integrals profiles by the pulsed wire technique. After removal of the dispersion effects, this might substitute in the future the Hall sensor mapping, allowing to access smaller vacuum gaps (< 3 mm).
- Moving stretched wire technique to precisely determine the values for the first and second field integral of the SCU, and to adjust correction coil currents to minimize the field integrals.

Figure 1 shows the design drawing of the measurement components mounted in UHV chambers and attached to a SCU vacuum vessel with superconducting coils. In the final arrangement, the support structure of the coils maintains the vacuum-gap height of 7 mm. The first ID to be measured will be the SCU15 mentioned before.

Local Field Measurement Components

For local field measurements one Hall sensor, calibrated at low temperatures, is mounted on a sledge (70 mm x 30 mm x 3.5 mm), and guided along the whole length of the magnetic structure by a 2 m long accurately machined guiding rail (Fig. 2).

Both components are manufactured out of ceramic material to be suitable for UHV applications, very stable, non-magnetic, and to avoid impacts of different shrinking. In the SCU15 the guiding rail is laying on the bottom surface of the liner, which separates the isolation vacuum from the UHV. In new undulator types as SCU20 the spacer in the liner, which defines the vacuum gap, can be used to guide

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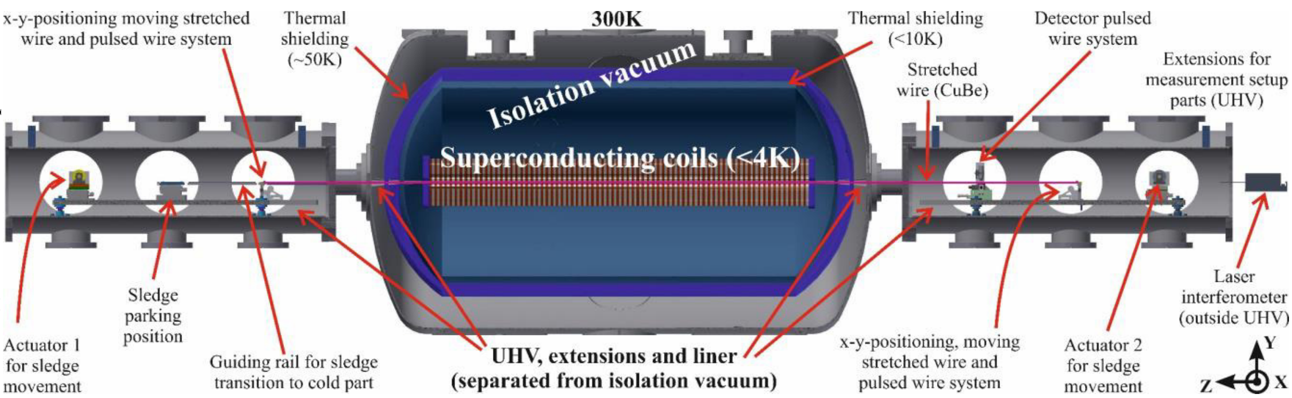

Figure 1: Design drawing of the measurement setup for superconducting undulators attached to a SCU-dummy-cryostat.

the sledge. Due to the precise machining of the ceramic rail the dislocation of the Hall sensor in the height of the gap is < 100 µm and has a negligible impact on the measurement setup accuracy [5]. The Hall sample is powered by a Keithley 6220 constant current source and the Hall voltage is measured by a Keithley 2700 digital multimeter.

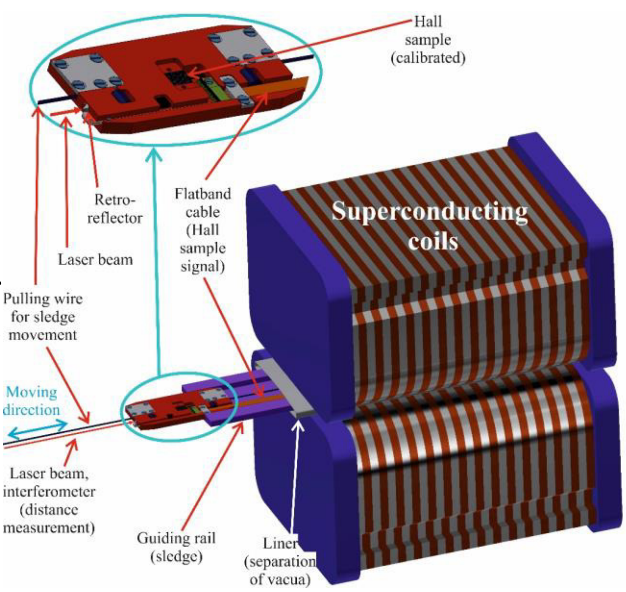

Figure 2: Design drawing of superconducting coils with local field measurement components.

The movement of the sledge in both directions is enforced by wires fixed to each side of the sledge. The wires are pulled by two Phytron UHV stepper motors located in the UHV extensions, which work synchronously and spool the wire on a bobbin (Fig. 1-3). The magnetic field data is acquired step-wise with steps down to 50 µm. To measure the position of the sledge along the moving axis precisely (resolution 1 µm), a laser interferometer is attached outside the vacuum chambers, and the beam is reflected by a retroreflector inserted in the face side of the measurement sledge (Fig. 1, 2). At both ends, the ceramic rail is in-line with rails in the outer UHV chambers to move the measurement sledge to the room temperature region, where it stays while measuring with the stretched wire (Fig. 1, 3).

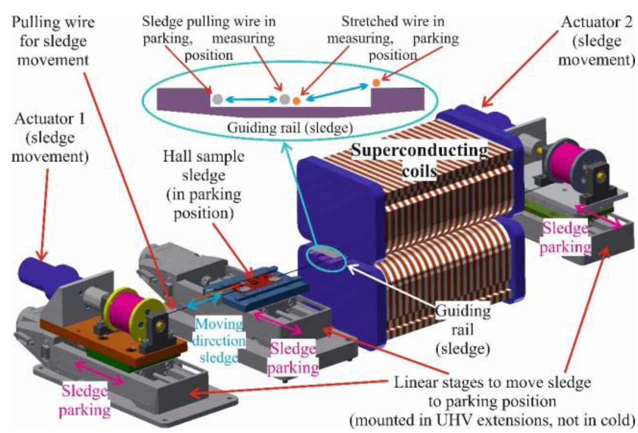

Figure 3: Schematic drawing of the arrangement of the measurement components for local field measurements.

Field Integral Measurement Components

The change in angle and position of the electron beam at the exit of the ID are proportional to the first and second field integral respectively. To keep the ID transparent for the electron beam the field integrals produced by the ID have to be minimized. 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 perpendicular to the beam axis (moving wire technique) or the wire stays at the beam axis and a high voltage current is pulsed through (pulsed wire technique).

The main advantage of the described setup is the possibility to measure the local field and field integrals within the same cooldown. To perform measurements with the stretched wire, the ceramic sledge is placed in the parking position and moved horizontally out of the middle, together with the pulling wires by three linear stages (Company PI, type L-509), to leave space for the stretched wire (Fig. 3). When measuring the local magnetic field distribution, the stretched wire is moved out of the center by piezo stages to leave space for the Hall sample sledge and the pulling wire, which then can be moved from the outer UHV chambers to the ceramic guiding rail (Fig. 3, 4).

In case of the moving wire measurement, the induced voltage during the movement of the wire in the magnetic field of the undulator is proportional to the field integrals.

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Pulsing an electrical current through wire leads to a deflection of the wire along the magnetic structure, according to the magnetic field strength of the individual poles of the ID. Because of the restoring force of the tensioned wire, the current pulse creates a travelling wave that moves down the wire in the magnetic field, where it passes a detector, which records the wire displacement. It is necessary to place the detector at a distance from the closest end larger than half of the ID length. The reason is to avoid superposition from the signal reflected from the two ends at the detector. The amplified detector signal is recorded by an oscilloscope and will be scaled to units that represent the magnetic field. One measures, spatially resolved, the development of the field integrals along the beam axis.

As shown in Fig. 4 the wire (Copper Beryllium, Ø 125 µm) is tensioned between two piezo x-y-positioning systems (Company SmarAct) which allow the adjustment of the wire to the center of the magnetic structure and act as moving stages during measurements. The piezo unit system enables a movement of 50 mm horizontally in x-direction and 30 mm vertically in y-direction with a resolution < 1 µm. A constant force spring with a strength of 15 N applies the tension to the wire. The tension value is figured out from experiences with the measurement setup CASPER II. Calculations from [6] showed, that a tension of 600 g led to 82 µm sag which has a negligible effect on the measurement accuracy.

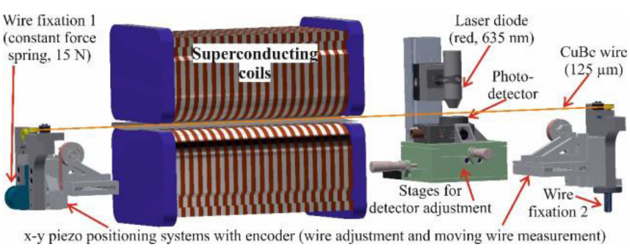

Figure 4: Measurement components for field integral measurements with a stretched wire.

For the new setup the distance between the end points of the wire is ~3.92 m (Fig. 1) because of the length of the complete undulator cryostat vessel and additional space in the UHV extensions. Following the calculations in [6], to achieve a sag of 100 µm with a CuBe wire of Ø 125 µm and a distance of 3.92 m, one needs a tension of 12.3 N. We use 15 N to be on the save side. A future development would be the attachment of a load cell on a linear stage to enable a change of the wire tension according to experimental requirements.

Typically, the specifications for field integrals of superconducting IDs show values ~10^{-5} Tm or Tm^2, respectively. The induced voltage signal for these values during the movement of e.g. $\Delta x = 1$ mm, while performing moving wire measurements, is quite small (~10 nV). Therefore, the signal will be pre-amplified by a DLPVA voltage amplifier (Company FEMTO), before acquired with a Keithley 2182a Nanovoltmeter.

A faster approach to determine the magnetic properties, which can also be applied to narrow gap IDs, is the pulsed wire technique [7]. The interaction of the current pulse with the magnetic field results in a displacement of the wire, which is related to the magnetic field distribution. Applying a short pulse of duration $\Delta t << \lambda_U / 2\, c_0$, where λ_U is the period of the ID and c_0 the wave speed at zero dispersion, the movement of the wire is proportional to the first field integral. Applying a pulse with a length $\Delta t > L / c_0$ where L is the length of the ID, the movement of the wire is proportional to the second field integral. Typical pulse durations derived from room temperature tests are 2 µs for short pulses and 40 ms for long pulses.

The pulse is provided by a Stanford Research Systems DG 535 pulse generator, This pulse is combined with the output of a FUG MCP 350-1250 high voltage power supply to drive the current with a voltage of ~1000 V through the CuBe wire. As shown in Fig. 4, the moving wire piezo stages are used to tension and place the wire to the measurement position on the magnetic axis of the ID. To detect the wire displacement an ultra-low noise laser diode module from Coherent, emitting at 635 nm, is aligned to a Thorlabs silicon photodetector (DET10A/M) with a rise time of 1 ns. The wire displacement caused by the pulse, changes the exposure of the detector with time and the detector output signal is amplified (DLPCA-200 current amplifier, Company FEMTO). To maximize the output signal of the photodetector the alignment to the laser diode can be changed by combined x-y-linear stages (Fig. 4). The amplified output signal, connected to an oscilloscope is added up and displays the field integrals in the time domain. After correcting for dispersion both field integrals and the longitudinal local field profile can be extracted [8].

CONCLUSION

In this contribution, we present and describe a new measurement setup to quantify the local magnetic field profile as well as field integrals of superconducting IDs when already mounted in the final cryostat and before installation in a storage ring. Within the same cooldown, three different measuring techniques are applied: local field mapping with a Hall sensor, the moving stretched wire and pulsed wire technique.

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