IN-VACUUM, CRYOGEN-FREE FIELD MEASUREMENT SYSTEM FOR SUPERCONDUCTING UNDULATOR COILS

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Abstract

The performance of superconducting insertion devices (IDs) depends strongly on the magnetic field quality. Before installing IDs in synchrotron light sources the characterization and precise measurements of their magnetic properties are of fundamental importance. Improvements in magnetic field measurement technology of conventional, i.e. permanent magnet based IDs, made significant progress during the last years and push the capabilities of synchrotron light sources. For superconducting IDs similar major developments are necessary. As a part of our R&D program for superconducting insertion devices we perform quality assessment of their magnetic field properties.

This contribution describes details and challenges of the cryostat and measurement setup assembly 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. The focus will be on the outcome of the final acceptance test together with results of first tests performed with a conduction cooled mock-up coil.

INTRODUCTION

For an undulator the important figures of merit are the field integrals and the phase error, where the field integrals along the beam axis should ideally 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. In order to obtain a photon beam with high brightness all photons emitted along the trajectory of one single electron must have a constant phase relation so that they interfere constructively. 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 do not interfere constructively.

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

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 was delivered to the KIT in July 2011. In this contribution we describe the final measurement setup of CASPER II together with the final acceptance test of the cryostat and first quench tests with a short conduction cooled mock-up coil.

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THE CRYOSTAT

In order to perform tests with superconducting coils in a similar arrangement as in final IDs, where they are usually conduction cooled, the inner part of the cryostat is in vacuum. The absence of liquid helium offers the flexibility to apply 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.

Figure 1 shows a side view and a cross section of the cryostat vacuum chamber. The cryostat has a shell-like structure to facilitate the exchange of the coils. It consists of 3 plates at 300 K, 80 K and 4 K (Fig. 1b), with respective shields and two further intermediate shields (an uncooled one and one at 50 K). Cooling the 80 K plate and pre-cooling the 4 K plate will be done via heat exchangers and LN_2. To reach the final temperature on the plate four 2-stage cryocoolers are installed. To power the main coils and/or additional correction coils 8 current leads with 500 A each are mounted (Fig. 1a). A detailed description of the cryostat is given in [2].

MEASUREMENT SETUP

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 and are arranged horizontally as in the final ID.

Hall Sample Measurements

For local field measurements three Hall sensors are placed on a brass sledge which will be pulled through the gap along the undulator coils (Fig. 1, 2). 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 (see Fig. 1a). The laser is reflected by a mirror on the Hall sensor sledge. 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 (Fig. 1, 2).

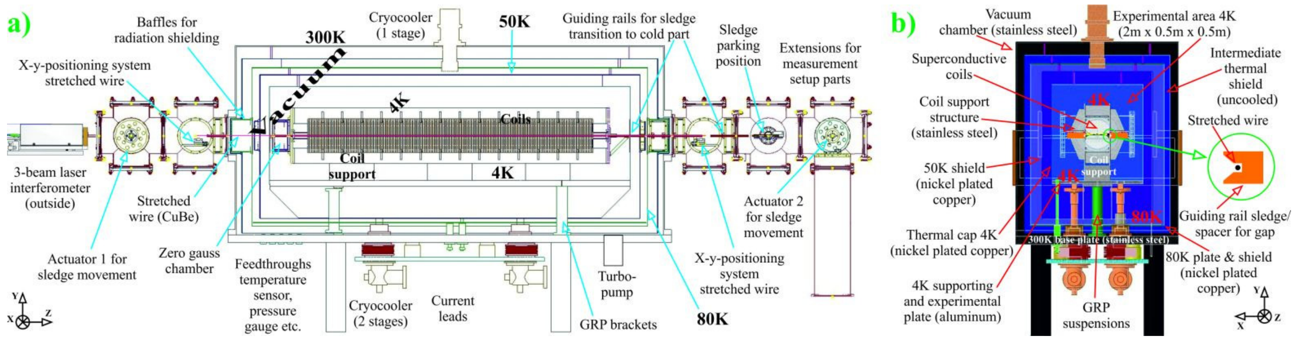

Figure 1: Side view (a) and sectional view along z-axis (b) of CASPER II showing the different temperature regions and the equipment for local and integral field measurements.

The motors work synchronous and coil the wire on a bobbin. The precise position of the sledge and of the Hall samples along the moving direction is measured by a laser interferometer SIOS SP-2000-TR (Fig. 1a) within 1µm.

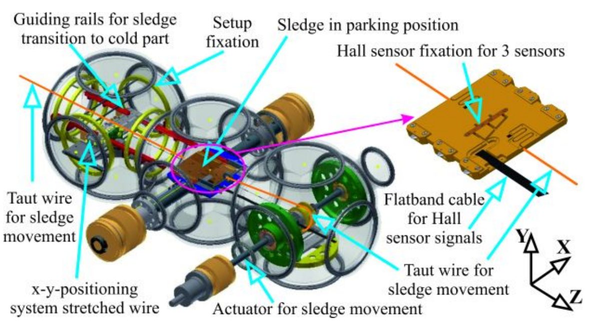

Figure 2: Schematic drawing of the local field measurements setup.

In order to measure the field in the middle of the gap the sledge is guided by sliding rails (Fig. 1a, 2), which are part of the coils support structure and have extensions to guide the sledge to the room temperature region (Fig. 1), where it has to be parked while measuring with the stretched wire. To check the Hall sensor calibration at operation temperature (4K), a zero gauss chamber made out of Cryoperm is foreseen to shield the sensors from stray fields.

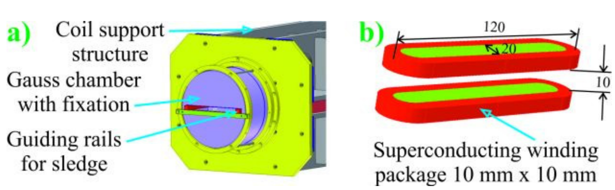

Figure 3: Planned components to check Hall sample calibration: a) zero Gauss chamber, b) racetrack coils.

It will be mounted directly at the end support structure (Fig. 1a, 3a). To test the field dependence of the samples up to 0.7T a pair of superconducting racetrack coils is foreseen (Fig. 3b).

Stretched Wire Measurements

It is important to achieve small field integrals to keep the undulator transparent for the electron beam. The first and second field integrals can be measured by means of the stretched wire technique.

In our system a Copper-Beryllium (CuBe) wire with 125 µm diameter will be used. For movement it will be fixed to x-y piezo stages in the extensions on both sides of the cryostat (Fig. 1) which can move synchronous ± 65mm in x-direction and ± 20 mm in y-direction.

The wire will be kept straight by applying a constant force of 6.2 N by a spring fixed to one stage (Fig 4).

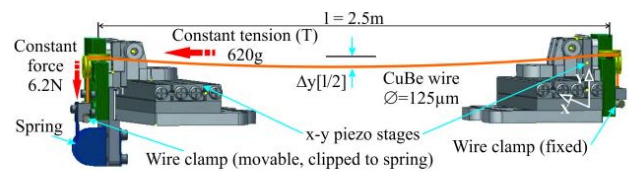

Figure 4: Sketch of the stretched wire setup.

An error consideration for the field integrals we get from [3]. With a value for the mass density per unit meter of CuBe (ω_{CuBe}=64 mg/m) and the values shown in Fig. 4, one achieves a sag of

$$\Delta y\left(\frac{l}{2}\right) \cong -\frac{\omega_{CuBe}\, l^2}{8\,T} = -82\ \mu m\,. \quad (1)$$

The resulting field integral error for λ_U=0.015m is [3]

$$\frac{\Delta I_y}{I_y} \approx \left(\frac{2\pi}{\lambda_U}\right)^2 \cosh\left(\frac{2\pi}{\lambda_U}\Delta y\right)\cdot\frac{\Delta y^2}{2} \approx 5.9\times10^{-4}\,, \quad (2)$$

which is good enough for our purposes.

FINAL ACCEPTANCE TEST

After delivery of the cryostat to the KIT the final acceptance test has been performed where the functionality of all electrical and mechanical parts has been proved.

To simulate the final temperatures reachable at the superconducting coils during the final measurements we arranged a 60 cm long brass block thermally disconnected in the middle of the 4 K region (Fig. 5). It was cooled via a 750 mm copper braid connected to the second stage of one cryocooler cold head.

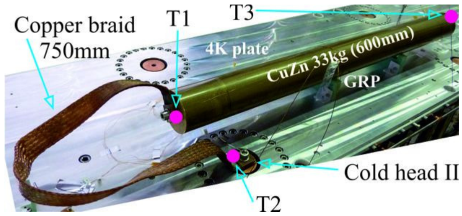

Figure 5: Picture of the 4 K plate with the test setup for the final acceptance test.

Three calibrated CERNOX temperature sensors were clamped to this setup to measure temperature T1 to T3 (see Fig. 5). As shown in Fig. 6, cooling the system for the first hours (0h < t < 7h) with liquid nitrogen works quite well and the temperatures change fast. After ~ 40 hours the temperature of the 80 K shield stabilizes simultaneously with the temperatures at the cold head (T2) and at the 4 K plate.

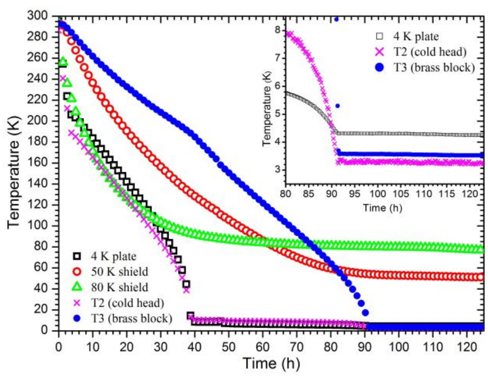

Figure 6: Graph with time dependence of selected temperatures during final acceptance test.

It takes ~50 h longer to reach the final temperature of the test setup. This is mainly due to the small and long copper braid connection of the brass block, which will be changed to test future coil arrangements.

The inset of Fig. 6 shows the crucial final temperatures of the 4 K components and one can nicely see how they stabilize at the same time at 3.4 K (T2) and 3.6 K (T3). The 4 K plate reached 4.2 K.

MOCK-UP QUENCH TESTS

In the new SCU demonstrator to be tested at ANKA and under development in collaboration with the company Babcock Noell GmbH (BNG) the coils will be conduction cooled by cryocoolers [4]. Quench tests on a 10-plate mock-up coil resembling the final SCU demonstrator coils and provided by several temperature sensors along the cooling line have been performed.

The cooling was performed as during the final acceptance test. The time to cool down decreased to ~70h because of an improved cooper braid connection to the cold head (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.

In Fig. 7 (inset) the temperatures at the cold head and at the coil are reported as a function of time for several quenches. 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.

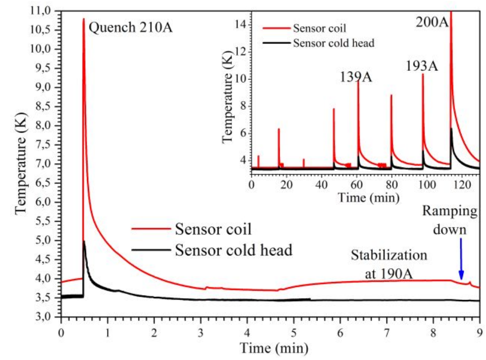

Figure 7: Temperatures over time during quench tests at selected measurement points.

After a quench the coil recovers to the baseline temperature in about 3 minutes. The maximum quench current was not reached as the test was limited to 210 A (Fig. 6). This value is well above the design current of 186 A, and the foreseen operating current of 150 A of the new ANKA SCU demonstrator. The quench at 210 A is due to superconductor warming after ramp-up is completed, attributed to the presence of several resistive joints in the coil. At a current of 190 A we observed that the temperature stabilizes after a rise of about 0.2 K.

CONCLUSION

An increasing interest in superconducting undulators with high magnetic field quality for the next generation of synchrotron light sources was the motivation to design and build a horizontal, helium-free, in-vacuum field measurement system for local and integral field measurements to measure coils up to 2 m length. The cryogenic vacuum system outperforms the required temperatures for operation.

Quench tests performed with a 10-plate mock-up successfully confirmed the functionality of CASPERII, already demonstrated in the final acceptance test of the device.

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