CASPER- A magnetic measurement facility for superconducting undulators

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Abstract. For a given gap and a given period length superconductive cold-bore undulators have a higher field strength compared to permanent magnet undulators. The measurement of the field and the field quality in the cold bore is demanding since the position of the Hall-probes have to be precise within a few microns over a distance of one to two meters. At the Forschungszentrum Karlsruhe two measuring facilities are under construction which allow to measure short mock-ups and undulators with a length of up to two meters. In this paper the two devices called CASPER (ChAracterization Setup for Phase Error Reduction) are described.

1. Introduction

Undulators are installed in the straight sections of synchrotron light sources. The field is generated either by permanent magnets or superconducting wires. Superconducting undulators are electrically tuneable and have higher field strength for the same gap and period length than permanent magnet undulators [1]. In April 2005 a 100 period superconducting undulator with 14 mm period length (SCU14) was installed at ANKA [2] and operates successfully since that time [3]. The spectral properties of the synchrotron radiation produced by a superconducting undulator depend mainly on the quality of the magnetic field. In order to obtain a photon beam with a high brightness the photons emitted by a single electron in the undulator have to interfere constructively. A prerequisite for the interference is that all the photons emitted along the trajectory of a single electron have the same wavelength and a constant phase relation. The wavelength and the phase are determined by the period length, the field strength in this period and the beam energy. If one of the parameters deviates in one or several periods photons produced in these periods can not contribute constructively to the radiation. As a result the emitted photon beam has a larger linewidth and the brilliance is reduced. In general, the measure for the field quality is the phase error [4]. In a perfect undulator after each period the difference between the photon phase and the phase of the oscillating electron is identical. In the case of mechanical errors this phase value varies. The phase error is the root mean square of the individual phase differences in the \(n\) undulator periods:

\[ \text{Phase Error} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left( \phi_i - \phi_0 \right)^2} \]

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\Phi_{error} = \sqrt{\frac{\sum_{i=1}^{n} (\Phi_i)^2}{n}}
\]

where \( \Phi_i \) is the phase error in the individual period.

The field errors are mainly caused by mechanical errors since the current in the superconducting wires is the same for each period. First ideas for the phase error correction for superconducting coils [5], the so-called electrical shimming, have been developed [6] at ANKA. One idea is to add superconducting correction wires. The shimming wires are thin wires parallel to the existing ones which are powered separately (fig. 1). Phase error correction ideas with additional correction coils will be tested in CASPER.

In order to measure and correct the field errors at 4.2 K two devices are under construction at the Forschungszentrum Karlsruhe: a field measuring system for short test coils and mock-ups and a measuring facility for coils up to 2 meters. At the test system for the mock-ups the whole device together with the field measuring Hall probes are in a liquid helium bath. This system will be mainly used for the development of new concepts of superconducting undulators. The second test system allows to measure the magnetic field of undulator coils up to a length of 2 meters. The coils in this system are indirectly cooled and the measuring Hall probes are in vacuum. The vacuum cold bore design also allows to measure field integrals by the stretched wire method.

![Figure 1. Principal idea of local phase shimming [5, 6]. With two additional wires left and right of the pole, the magnetic field is changed in this pole. The field outside the pole remains almost unchanged.](image)

2. Magnetic field measurement facility for undulator mock-ups and superconducting coils

The test system was designed (fig. 2) at ANKA at Forschungszentrum Karlsruhe and is manufactured by CryoVac, Inc., in Troisdorf, Germany. A similar device was build by a group from Brookhaven National Laboratory [7]. The cryostat has an external diameter of 550 mm and a height of 1825 mm. The inner diameter of 370 mm allows to host all previously built mock-ups. The cryostat has a cylindrical shape with a flat top and a flat bottom. On the bottom of the LHe vessel (vacuum side) an electric heating plate together with a temperature sensor is installed in order to evaporate the liquid helium. The probes and the top are moved by a crane. The probe is fixed to the intermediate
supporting plate of the cryostat. The evaporated helium is collected and recovered by a pipe system. The stainless steel helium-vessel of the cryostat is surrounded by a vacuum chamber and a nitrogen-vessel.

Two pairs of vapour-cooled current leads for maximum 1500 A and 500 A provide the most efficient way to transfer current from 300 K to 4.2 K. The current leads consist of copper rods in the room temperature section and high temperature conductors in between 60 K and the 4.2 K section.

3. Mock-up coil prepared for field measurements

Up to now superconducting undulators with NbTi wires were tested extensively with beam [3, 5]. The reason is that undulators with NbTi wires are easier to handle then undulators with Nb3Sn wires. Several institutes built short mock-ups with Nb3Sn wires in order to investigate the field and its quality [3, 8]. For Nb3Sn wires the transition temperature, the critical field and the critical current densities are higher compared with NbTi strands. Recently, a Nb3Sn mock-up coil for demonstration was built at ANKA. Fig. 3 shows a photo of 14 mm period Nb3Sn mock-up coil before the heat treatment. This mock-up was designed by ANKA and built by Babcock Noell GmbH. The grooves have a cross section of 5 x 5 mm filled with 30 turns per groove. The Nb3Sn filaments are in a copper matrix. The wire diameter is 0.83 mm and the non Cu volume is 53% ± 3%. The wire is insulated by glass with a thickness of 130 µm ± 15 µm.

Figure 2. Cut through the cryostat assembly together with mock-up coils and Hall probe sledge. On the sledge several Hall probes are mounted for mapping the magnetic field.
Figure 3. Nb$_3$Sn undulator mock-up designed by ANKA and built by Babcock Noell GmbH. The period length is 14 mm

4. Hall probe sledge and calibration coils

Three Hall probes and the temperature sensor are mounted on the sledge (fig. 4). The commercially available Hall probes have an active area of 0.0025 mm$^2$. The Hall probes are calibrated for the operation at 4 K. The measuring range is ± 5 T for an operating temperature between 1.5 and 350 K. The Hall excitation current for the sensors is delivered by a precision current source and the Hall voltage is measured by a digital multi-meter. The Hall probe sledge is attached to a fibreglass guide tube. The cryostat temperature profile is measured and the thermal expansion of the fibreglass is corrected in order to obtain the accurate position of the Hall probes. The Hall probe sledge is equipped with an electrical contact to mark the zero point of the magnetic field scan. The Hall probe array is driven by the computer controlled stepper motor. The speed is variable from 0 to 600 mm/min and the spatial resolution is 3 µm.

The Hall probe ensemble is moved through the vertical centre of the undulator gap and is guided by rails. The Hall probes are placed on a so-called flip plate. A flip plate can rotate the Hall probes as shown in fig. 4. This design allows to measure the effect of field symmetry and to obtain a zero-field value which can be further subtracted from all voltage values in the calibration tables.

Figure 4. The Hall probe sledge together with Hall probes and temperature sensor. The sledge is equipped with a flip plate, so the field symmetry can be measured.
In addition, the measuring system is equipped with Helmholtz calibration coils which are attached directly to the mock-up assembly. They allow to calibrate the Hall probes in-situ at liquid helium temperatures. The coils are made by a 54 filament NbTi wire. The dimensions of the rectangular wire are $0.46 \times 0.72$ mm. Each coil has $8 \times 8$ layers. A 500 Ampere power supply provides the current to the coils. The maximum magnetic field is 1.89 Tesla at a current density of 1200 A/mm$^2$.

5. Preliminary design for a magnetic measuring facility for coils with a maximum length of 2 meters

A horizontal cryostat for up to 2 m long coils is under construction. This will allow to measure both the local field with Hall probes and the field integrals with the well established stretched-wire technique (fig. 5) [9]. The coils are surrounded by a liquid helium tank which cools the coils indirectly. The coils are separated by two Cu bars which have two functions. They are used as spacers for the undulator coils and transport the cooling power from the liquid helium tank to the coils. A gap is left between the two copper bars to measure the local field and the field integrals. In this gap the sledge with Hall probes shown in fig. 6 can be moved or a stretched wire can measure the field integrals since the gap is in vacuum. The access to the gap is provided by the guide tube from the front end of the cryostat. The gap will have a fixed value. The outer temperature shielding is provided by a liquid nitrogen tank.

![Image](image.png)

**Figure 5.** The First design study of a horizontal test facility for superconducting undulator coils up to a length of 2 meters. The coils are cooled indirectly by a liquid helium tank. The gap is in vacuum so that both the field can be mapped with Hall probes and field integral measurements can be performed for instance with the stretched wire method.

6. Conclusion

A new test facility for the short mock-ups has been successfully developed, fabricated and a first experimental validation of the cryostat at cryogenic conditions was performed. The magnetic measurement assemblage is to be verified with the existing mock-up coils. A preliminary design of a magnetic facility for coils with the maximum length of 2 meters has been presented.
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