ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA027

FIRST CHARACTERIZATION OF A SUPERCONDUCTING UNDULATOR MOCKUP WITH THE CASPER II MAGNETIC MEASUREMENT SYSTEM

S. Gerstl[#], S. Casalbuoni, N. Glamann, A. Grau, T. Holubek, D. Saez de Jauregui, R. Voutta, ANKA Synchrotron Radiation Facility, Karlsruhe Institute of Technology, Karlsruhe, Germany
C. Boffo, T. Gerhard, M. Turenne, W. Walter, Babcock Noell GmbH, Würzburg, Germany

Abstract

Superconducting insertion devices (IDs) can reach, for the same gap and period length a higher field strength compared to permanent magnet IDs. Their performance depends strongly on the magnetic field quality. While the magnetic measurements technology of permanent magnet based IDs made significant progress during the last years, for superconducting IDs similar major developments are necessary. As a part of our R&D program for superconducting insertion devices at the ANKA synchrotron radiation facility a measurement setup for conduction cooled superconducting coils with a maximum length of 2 m was built and commissioned. In the CASPER II (Characterization Setup for Phase Error Reduction) facility (see Fig. 1) the magnet coils can be trained and tested for maximum current and field quality, including the local field distribution as well as the first and second field integrals. In this paper we shortly describe the CASPER II setup and focus on the capability of this measurement device by presenting the results of a superconducting undulator mockup with a period length of 20mm.

INTRODUCTION

The performance of insertion devices (IDs) depends strongly on their magnetic field quality. It is of fundamental importance to characterize magnetic field properties of IDs accurately before installation in synchrotron light sources. While for permanent magnet IDs, commercially measuring systems exists, for the characterization of superconducting IDs they are not available. ANKA and Babcock Noell GmbH are pursuing an R&D program aiming to develop superconducting undulators (SCUs) for third and fourth generation light sources [1]. The SCUs developed and under development with BNG make use of NbTi superconducting wire and are conduction cooled. In order to characterize the magnetic field properties of these conduction cooled SCUs, the CASPER II facility has been developed at ANKA [2, 3].

The CASPER II facility is a horizontal test stand where up to 2 m long superconducting coils can be measured. The setup is cryogen free. The coils under test are put on an aluminium table in a high vacuum environment and surrounded by a shell-like structure of different temperature shields. Cooling is provided by four 2 stage cryocoolers from Sumitomo with a total cooling power of 5.5 W. An additional one stage cooler from Oerlikon is connected to the 80 K shield. In total eight 500 A current leads are installed to provide power to the main magnet and its correction coils.

For magnet training two switchable bipolar 1500 A power supplies from Bruker in conjunction with an in house designed quench detection system (built by the Institute for Data Processing and Electronics at the KIT) and a fast data acquisition system from National Instruments is available.

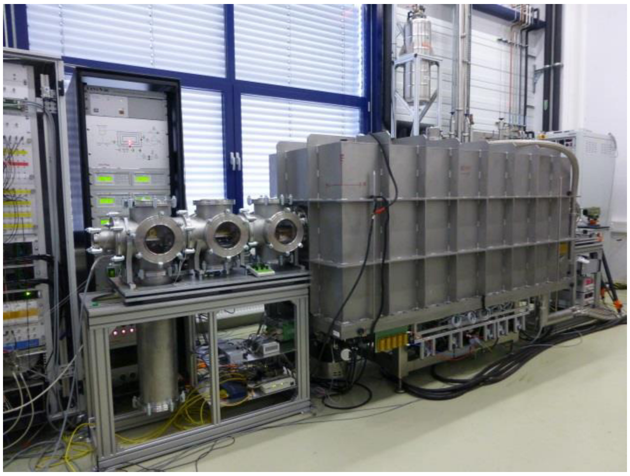


Figure 1: Picture of the CASPER II measurement system.

The local magnetic field perpendicular to the beam axis is measured by using 3 Hall probes, which are placed next to each other on a brass sledge. The Hall probes are placed at different horizontal positions in order to characterize a good field region of ± 10 mm. The sledge is guided by very precisely machined rails through the magnet and stepwise moved along the beam axis. To determine the position of the sledge a laser interferometer with a submircometer resolution is used. Further details can be found in Ref. [3].

For assessment of the vertical and horizontal first and second field integrals a piezo stage driven stretched wire setup is installed.

The full control and readout of the measurement system is programmed with LabView.

In this contribution we describe the CASPER II facility and its capabilities by presenting the results of the magnetic characterization of a 300 mm long prototype of the SCU20, a superconducting undulator with a period length of 20 mm under development within the collaboration between ANKA and BNG for use at the NANO beamline. An overview of the main features of the design is given in Ref. [4].

stefan.gerstl@kit.edu

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA027

MAGNET TRAINING

In the CASPER I bath cryostat [5], the SCU20 mockup coils where successfully powered above the nominal current of 380 A and up to 400 A, without quenching in liquid helium. Afterwards the prototype was tested in the CASPER II facility. Similar to the final device the superconducting coils are in horizontal configuration and conduction cooled. The coils are equipped with voltage taps (VT), which divide the coils in subsections of three winding packages. By measuring the differential voltages on these VT the location of a quench event can be determined. To readout the voltages a National Instruments PXI system comprising 64 simultaneous sampled channels with a maximum sampling rate of 250 kHz per channel is implemented. The values recorded by the PXI system are stored into a circular buffer with a typical length of 1 s and a pre-trigger duration of 0.5 s. The trigger signal is provided by an in house designed quench detection system, which is sensitive to the voltage difference in the top (A) and bottom (B) coils of the magnet. During the magnet training the voltage limit for a quench event was set to ± 10 mV.

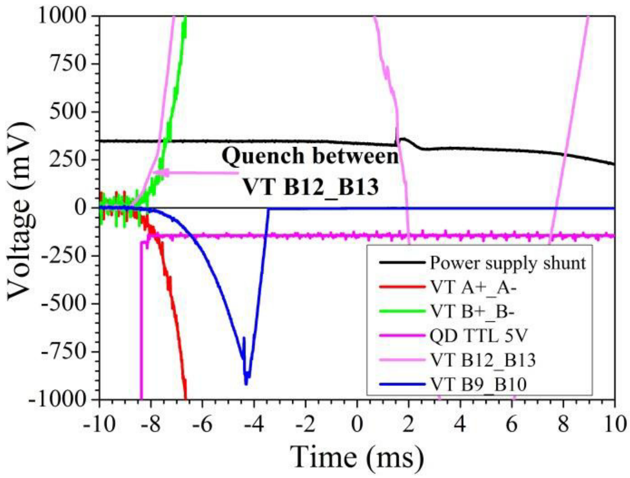
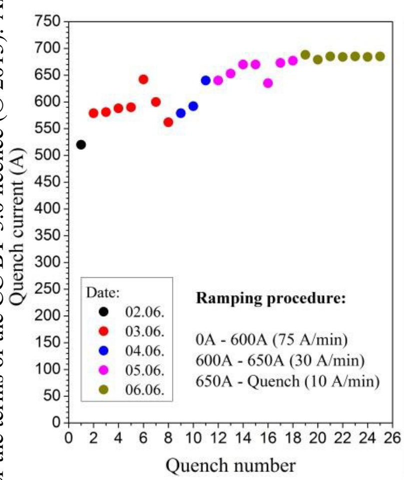


Figure 2: Typical voltage behaviour during a quench.



Number	Quench current (A)	Voltage taps
1	520	
2	579	VT A+_A1
3	581	VT B9_B10
4	588	VT B14_B15
5	590	VT B12_B13
6	642	VT B9_B10
7	600	VT A8_Joint
8	562	VT B12_B13
9	579	VT B12_B13
10	592	VT B12_B13
11	640	VT B12_B13
12	640	VT B12_B13
13	653	VT B16_B-
14	670	VT B11_B12
15	670	VT A+_A1
16	635	VT B12_B13
17	673	VT A+_A1
18	677	VT B9_B10
19	688	VT B10_B11
20	679	VT B12_B13
21	685	VT B16_B-
22	684	VT B12_B13
23	685	VT B16_B-
24	684	VT B16_B-
25	685	VT B16_B-

Figure 3: Quench current and ramping procedure during magnet training on the left and location of the quench in the table on the right.

A typical quench event at a current of 679 A is shown in Fig. 2. Hereby "QD TTL 5V" is the TTL signal of the quench detector, "VT A+_A-" the voltage across the top coil, "VT B+_B-" the bottom coil and "Power supply shunt" the voltage across the power supply shunt resistor, which is proportional to the applied current. "VT B12_B13" and "VT B9_B10" indicate two selected subsequent pairs of voltage taps. The voltage tap "VT B12_B13" rises within 2 ms above 1 V and can be identified as the quench region since it gives the first rising signal. From Fig. 2 it is also possible to infer that the voltage in coil "B" rises into the positive region, which is typical for a quench event, while the voltage in coil "A" increases towards the negative as a response to the breakdown of superconductivity in coil "B". After a quench in the coils the temperature rises within less than 1 minute to the maximum temperature, which remained well below 40 K during all tests. Due to the conduction cooling the SCU20 mockup needs approximately 50 minutes to cooldown to about 4.2 K after a quench. The minimum temperature reached without current in the coils was below 3.5 K.

Already at the first quench in CASPER II the magnet reached 520 A, which is almost 30 % above the nominal current of 380 A. At quench 19 (see Fig. 3) the magnet reached its maximum current of 688 A.

The table in Fig. 3 shows the quench locations determined with the described PXI system. It can be seen that the distribution of the quenches in the subsections of the magnet is random from quench number 1 to 22. The last three quenches occurred in the same region of the magnet, indicating that the electrical limit of the magnet is reached at around 680 A, which is more than 40 % above the design current for the full undulator magnet.

LOCAL FIELD MEASUREMENT

For the local field measurements three Hall probes are installed with a spacing of 10 mm perpendicular to beam

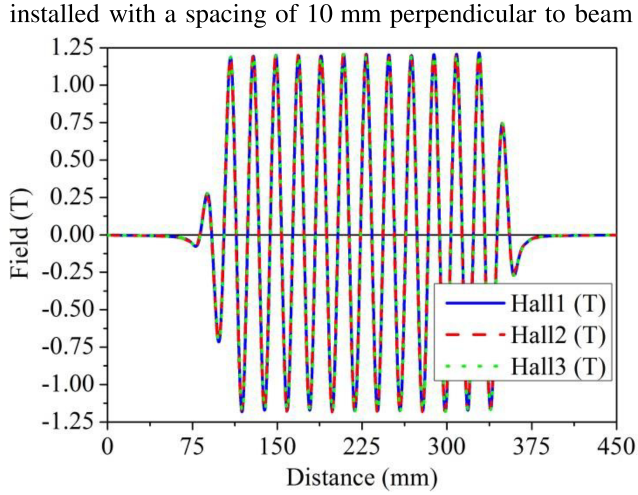


Figure 4: Local field map of the undulator mockup measured with three 10 mm spaced Hall probes.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA027

direction. We use Arepoc HHP-VP probes with a small active area of 50 µm x 50 µm. The calibration was done in house at the Institute of Technical Physics (ITEP) at KIT inside a Physical Property Measurement System (PPMS) from Quantum Design.

The calibrated Hall probes are mounted on a brass sledge, which is guided by two precisely machined rails. The sledge is pulled in beam direction with a stainless steel cable by two stepper motors. A retro reflector installed on the sledge makes it possible to precisely determine the position within less than 1 µm with the help of a laser interferometer. Figure 4 shows a local field map of the undulator mockup at a current of 375 A. The correction coils are powered with 4.75 A and 5.75 A respectively. The Hall probe measurement data is not taken continuous but step wise with an average step size of 50 µm every second. With a magnetic gap of 8 mm the superconducting undulator mockup reaches a peak field of almost 1.2 T.

INTEGRAL FIELD MEASUREMENT

For assessment of the first and second field integral a combined vertical and horizontal piezo stage system from SmarAct is installed on both ends of the measurement system. The travel of the vertical stages is ± 10 mm whereas the horizontal stages can be used in a range of ± 70 mm around the middle axis of the magnet. A 100 µm diameter copper beryllium wire is tensioned between the stages by a spring and moved inside the magnetic field created by the SCU20 mockup. For the readout of the induced voltage a combination of two Keithley Nanovoltmeter is used.

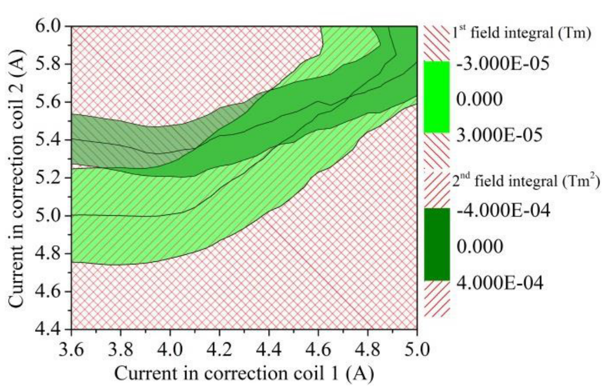


Figure 6: Color plot of the 1st and 2nd field integrals for different correction coil currents.

Figure 5 shows the distribution of 260 consecutive measurements of the first vertical field integral. During these measurements the current in the main coil was set to 375 A. The first correction coil was powered to 5 A and the second coil to 6 A. The two horizontal piezo stages before and after the magnet were moved in a parallel translational motion synchronously ± 2.5 mm around the magnetic middle axis in the vertical center with a speed of 5 mm/s. Each of the 260 values reported in Fig. 5 is obtained by averaging over several measurements of a single wire move from 2.5 mm to - 2.5 mm.

For the SCUs to be installed at ANKA the first vertical field integral is specified to be smaller than 3.0×10^{-5} Tm. With a precision of $\pm 3.5 \times 10^{-6}$ Tm the distribution of the histogram in Fig. 5 shows that the system is capable of measuring the required first field integral.

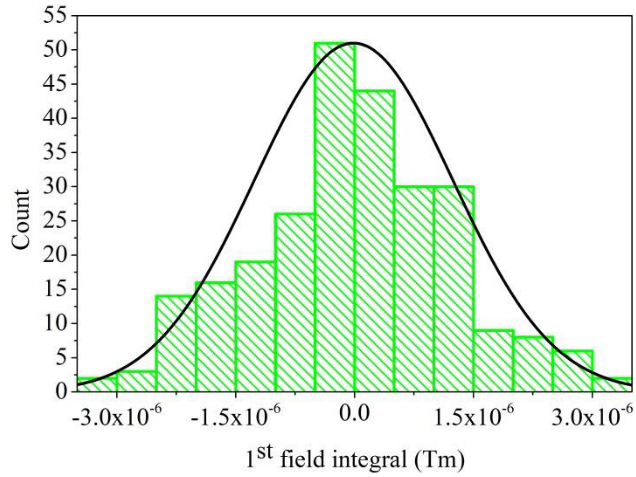


Figure 5: Distribution of 260 consecutive measurements of the first vertical field integral for a 375 A in the main coil, 5 A in the first and 6 A in the second corrector coil.

To minimize both the first and second field integral, the currents in the two correction coils are scanned within ranges of 1.6 A and 1.4 A. In Fig. 6 the result of such an optimization procedure is presented. The light green area in the plot shows the current values for the correction coils, which fulfil the limit of the first vertical field integral of $\pm 3.0 \times 10^{-5}$ Tm given by the specification. The dark green area indicates values which give a second field integral within the specified range of $\pm 4.0 \times 10^{-4}$ Tm^2. In the areas marked with red stripes at least one of the integrals is out of specifications. The overlapping green area gives the values where both field integrals are minimized and within specifications.

SUMMARY

The CASPER II magnetic measurement system has been commissioned using the 300 mm long SCU20 mockup and is ready to characterize conduction cooled superconducting undulator coils with a total length of up to 2 m. Magnet training as well as local and integral field measurements, can be performed within one cool down and a precision comparable to room temperature measurement systems.

REFERENCES

[1] S. Casalbuoni et al., WEBC3, IPAC'15, Richmond, VA. USA (2015).

[2] A. Grau et al., IEEE Trans. Appl. Supercond. **21-3**. 2312 – 2315 (2011).

[3] A. Grau et al., IEEE Trans. Appl. Supercond., **22-3**. 9001504 (2012).

[4] S. Casalbuoni et al., IEEE Trans. Appl. Supercond. 24-3, 4101905 (2014).

[5] E. Mashkina et al., J. Phys.: Conf. Ser. **97-1**, 012020, (2008).