TRAINING AND CHARACTERIZATION OF 1.5 m LONG CONDUCTION COOLED SUPERCONDUCTING UNDULATOR COILS WITH 20 mm PERIOD LENGTH

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Abstract

The Institute for Beam Physics and Technology (IBPT) of the Karlsruhe Institute of Technology (KIT), and Babcock Noell GmbH (BNG) are collaborating since several years on an R&D program on superconducting undulators (SCUs).

At the moment the collaboration is focusing on a SCU with 20 mm period length (SCU20) for ANKA, the test facility and synchrotron radiation source, run by the IBPT. The 1.5 m long undulator coils were tested in a conduction-cooled environment. This contribution describes the training and the thermal behavior of the coils.

INTRODUCTION

To produce high brilliant synchrotron radiation, many synchrotron light sources use insertion devices (IDs) [1]. The most commonly used technology in IDs makes use of permanent magnet blocks placed inside the beam vacuum of the storage ring, which create the alternating magnetic field required to produce the characteristic undulator radiation. A higher brilliance can be achieved when the magnet blocks are cooled with liquid nitrogen as in cryogenic permanent magnet undulators (CPMUs). Compared to CPMUs the SCU technology has the potential to reach for the same gap and period length an even higher field and therefore increase the spectral range and the brilliance of the emitted radiation.

Within an R&D program, running since several years between the Institute for Beam Physics and Technology (IBPT) at the Karlsruhe Institute of Technology (KIT) and its industrial partner Babcock Noell GmbH (BNG), SCUs for the storage ring ANKA, which is run by the IBPT, and 3rd generation light sources, are developed [2]. A full length device with 15 mm period length was installed and characterized at ANKA for one year [3]. At present the focus is set on a 1.5 m long, full scale device with a period length of 20 mm (SCU20) for ANKA, consisting of coils wound with round NiTi superconducting wires.

Before installing the coils in the final cryostat, they have to be trained, their thermal behavior and stability has to be tested, and their magnetic field properties characterized. For this purpose the CASPER II test facility was developed and built at the IBPT (Fig. 1) [4]. With this setup the coils are tested in a horizontal, in-vacuum, conduction cooled environment as when installed in the final cryostat. Along with the data acquisition instrumentation for quench tests and training of the superconducting coils, local field mapping with Hall samples and field integral measurements with stretched wire technique, can be performed.

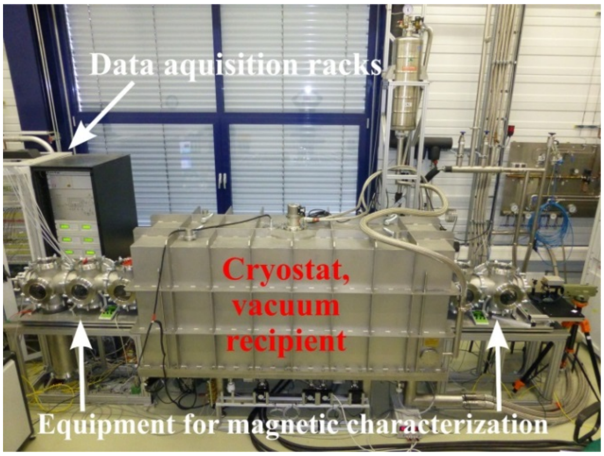

Figure 1: Measurement system CASPER II. The cryostat (vacuum recipient) and vacuum crosses (sideways), where the magnetic measurement components are mounted, together with the data acquisition racks.

Additionally the field integrals can be minimized by optimizing the use of the correction coils integrated in the main coils. Results of the magnetic characterization of the SCU20 coils are provided in [5].

COOLING THE SCU20 COILS

The CASPER II cryostat has a shell like structure with different temperature regions from 300 K of the vessel, to 4 K of the horizontal aluminium plate, where the coils are mounted.

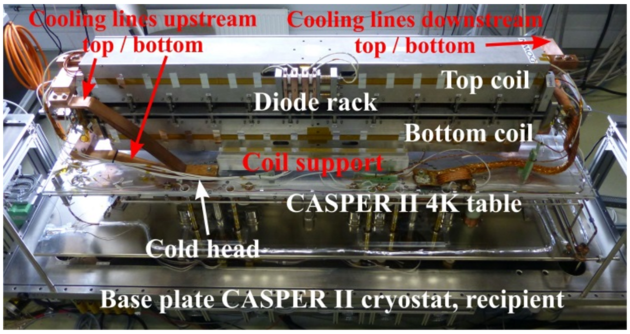

Figure 2: SCU20 coils with cooling lines attached, mounted with a support structure on the 4 K table of CASPER II.

Two cryocoolers, each with 1.5 W cooling power at 4 K, are used to cool down the coils separately from the

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other cryostat parts. The coolers are connected to the coils via copper sheets to ensure excellent thermal connection and thermal stability during the tests (Fig. 2).

There are several temperature sensors placed on the coils and along the cooling lines. Fig. 3 shows a typical temperature curve during a cooldown of the SCU20 coils.

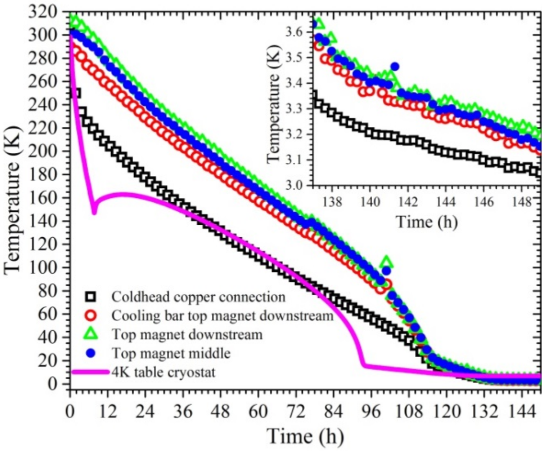

Figure 3: Time dependence of selected temperatures during cooldown of the SCU20 coils. The inset shows the temperatures along the cooling line from the cold head to the middle of the coils.

As one can see, the coils cool down independently from the 4 K table where the coils are mounted and reach after ~6 days a temperature between 3.1 K and 3.2 K. The 4 K table stays at a bit higher temperature, at ~6 K, because of the large heat intake from the outer shields. The inset of the graph shows the temperature distribution along the cooling line in the last part of the cooldown. The temperature gradient from the cold head to the magnet is 0.1 K and there is no measurable gradient along the magnet from the end (Top magnet downstream) to the middle (Top magnet middle) which proves the effectiveness of the cooling system of the coils.

TRAINING

Quench Voltage Pattern and Quench History

After reaching stable temperature conditions the training of the coils was performed. According to the specifications the required peak field on axis with a magnetic gap of 8 mm must be ≥1.18 T which is reached with an operating current of 395 A (1.187 T). The coils have been trained up to 400 A with ramping conditions as in operation in the storage ring, which means 300 s from 0 A to operating current with a maximum ramp rate of 137 A/min.

The SCU20 coils are equipped with voltage taps (VTs) which divide each coil electrically in 16 parts, consisting of ~10 superconducting winding packages. By analyzing the voltage drop along these subsections it is possible to determine the region in which a quench occurs. A National Instruments PXI system with 64 simultaneously readable channels with a maximum sampling rate of 250 kS/s is used to measure these voltage signals. The data acquisition of the PXI is started by a trigger coming from a quench detector. A typical acquisition time scale is 1 s including a pre-trigger time of 0.5 s. To read out the signals a LabView program is used.

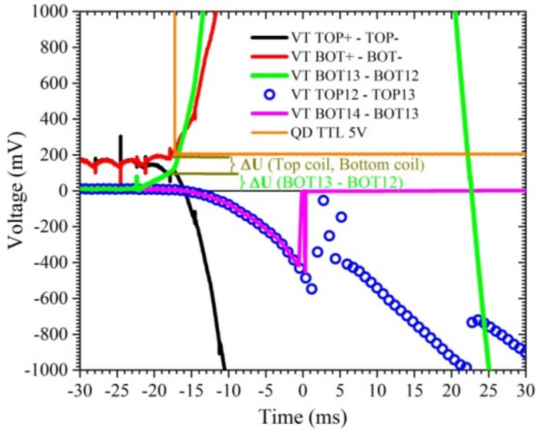

Figure 4: Voltage data of selected SCU20 coil subsections during a quench at 390 A taken with PXI data acquisition system.

Figure 4 shows a typical voltage reaction during a quench, which happened in the present case at 390 A. The “VT TOP+ – TOP-“, and “VT BOT+ – BOT-” lines show the voltage drop along the top coil and bottom coil, and “VT BOT13 – BOT12” etc. indicate the voltages between adjacent voltage taps which correspond to the subsections of the coils. The graph shows that the voltage rises first in the bottom coil and more precisely in the subsection between voltage tap “BOT13” and “BOT12”, whereas this region is assigned to be responsible for the quench. The rising potential difference in this section, ΔU(BOT13 - BOT12), affects directly the voltage difference between the coils, ΔU(Top coil, Bottom coil), and this unbalance triggers the quench detector if it is larger than the threshold voltage setting of 100 mV for longer than 10 ms (Fig. 4). As a response to the breakdown of the superconductivity in the bottom coil subsection “BOT13 - BOT12”, the voltage drop along the other coil and the other subsections (VT TOP12 – TOP13 etc.) increases to the opposite sign.

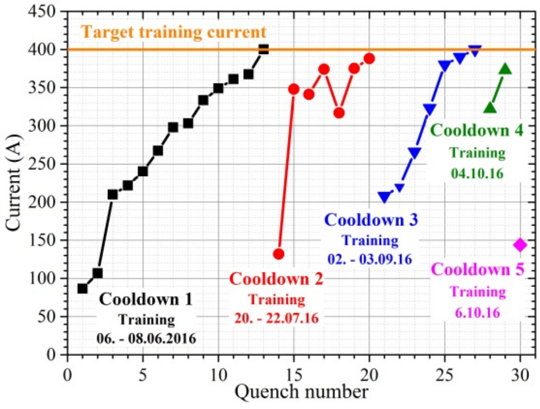

Figure 5: Quench history of the SCU20 coils.

The quench history, with overall 30 quenches throughout the measurement campaign, is shown in Fig. 5. The number of quenches needed to reach a stable current of 400 A is reduced after each thermal cycle. If once the target current is reached, no further quenches occur, even with faster ramp rates than needed for a complete ramp in 300 s, for instance 211 A/min.

Temperature Characteristics

During the training the temperature of the coils was recorded. After each quench the temperature of the coils rises within ~3 minutes to the maximum temperature. For quenches near the operating current this temperature reaches 18 K in the magnet where the quench occurred and 5 K less for the other magnet (Fig. 6).

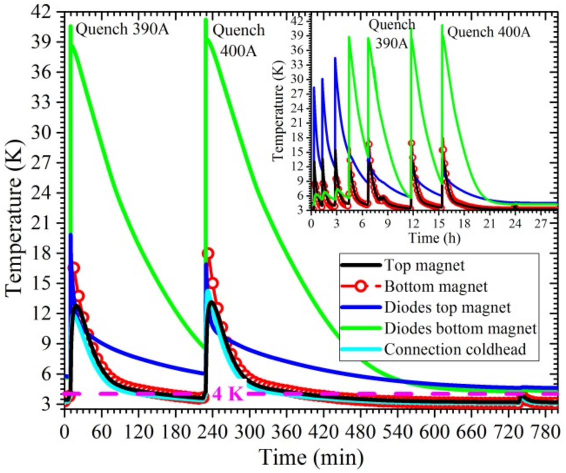

Figure 6: Temperature behavior during two quenches near the operating current. The inset shows the complete quench series of cooldown 3.

As shown in Fig. 6, a much higher temperature of about 41 K is observed for the quench protection diode packages directly after a quench. In case of a quench the stored energy in the coils has to be lead off fast in order not to damage the superconductor. This might take in the order of 100 ms according to the inductivity of the coils and the power supply design. Therefore the rectifier diodes with a forward voltage of 5 V, in cold conditions, are installed for safety reasons and connected electrically in parallel to the superconducting coils (Fig. 2). If the quench voltage is rising above the threshold voltage of the diodes, the arrangement ensures a direct discharge of the stored energy in parallel to the coils. This happens before the power supply is completely shut down, resulting in large heat dissipation in the diodes, as indicated in Fig. 6. The temperature rise of one diode cell, consisting of 6 diodes individually for one coil, is linked to the temperature rise of the connected coil (Fig. 6 inset).

The cooling of the coils is rather effective and after ~2 h the temperature of the coils is once again just above 4 K and the coils are ready to be powered again. Until the diodes reach this temperature again it takes ~8 h longer, but the higher temperature of the diodes has no effect on the coil performance when they are powered again.

Due to the non-linear inductivity of the coils in the low current and field range, where the magnetization of the iron yoke impacts the magnetic field, four different ramping rate steps are necessary to get to the operating current with safe quench detector settings and within 300 s.

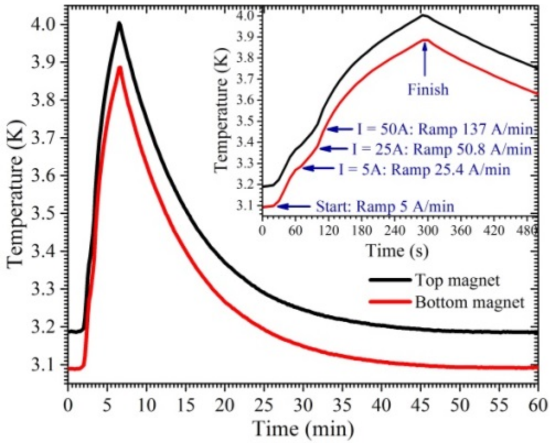

Figure 7: Temperature evolution during and after a ramp to operating current. The inset shows the temperature rise for the four ramping steps.

A typical temperature evolution during and after the ramping is shown in Fig. 7. The inset shows the four current ramping steps and the corresponding temperature rise. The overall temperature increase is about 800 mK for a complete ramp and after ~35 min. in constant maximum current conditions the initial temperatures are restored.

CONCLUSIONS

In the CASPER II test facility, run by the IBPT, the 1.5 m long coils for SCU20, the new superconducting undulator with 20 mm period length, have been characterized in a conduction-cooled, horizontal environment. The results of the training in terms of quench currents and temperature evolution of the coils are presented and the cooling concept of the coils has been proven. The specified magnetic field on axis of 1.18 T is reached for 395 A and further results of the magnetic characterization of the SCU20 coils are provided in [5]. The 1.5 m long SCU20 coils are ready for installation in the final cryostat.

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