IN VACUUM CONDUCTION COOLED SUPERCONDUCTING SWITCH FOR INSERTION DEVICES WITH VARIABLE PERIOD LENGTH

T. Holubek*, T. Baumbach, S. Casalbuoni, S. Gerstl, A. Grau, M. Hagelstein, D. Saez de Jauregui, ANKA, Karlsruhe Institute of Technology, Karlsruhe, Germany,
C. Boffo, W. Walter, Babcock Noell GmbH, Würzburg, Germany

Abstract

Switching the period length allows to increase the tunability of an insertion device (ID). This can be realized in superconducting IDs by reversing the current in a separately powered subset of the superconducting windings. In order to use only one power supply instead of two for the two circuits, reducing the thermal input to the device, work is ongoing at ANKA (ANgstrom source KArlsruhe) to develop a superconducting switch (SCS). In this work we present the results of the test of an in vacuum housed, conduction cooled SCS.

INTRODUCTION

Switching the period length allows to increase the tunability of an ID. In superconducting IDs, switching the period length can be achieved by reversing the current in a separately powered subset of the superconducting windings [1]. This idea is being implemented at ANKA [2, 3] for a device intended for the IMAGE beamline. Switching will be between an 18 mm period undulator and a 54 mm period length wiggler. We proved the feasibility of period length switching using a 9 pole mock up designed and manufactured by Babcock Noell GmbH (BNG) and showed that there is no need to retrain the magnet after each switch [4]. Within the ongoing R&D program at ANKA on superconducting IDs, we are working at the development of a conduction cooled superconducting switch (SCS) [5]. The implementation of a SCS allows to reduce the number of power supplies needed in superconducting IDs with switchable period length and consequently suppresses the thermal load to the device. We built a SCS following the classical electrical bridge concept successfully applied in a liquid helium environment [5, 6]. Instead of employing electrical resistors, the resistance of each circuit-branch is controlled thermally by a heater in good thermal contact with the circuit-branch to be switched from the superconducting to the normal state. A SCS can be used also to switch different correction coils eventually used in superconducting IDs.

Applications to conduction cooled cryogen free insertion devices as the ones under development at ANKA in collaboration with BNG [7] make use of cryocoolers, which have typically a cooling power of 1-1.5 Watts at 4K. For this reason, for our application we need a SCS which must not dissipate more than a fraction of a Watt.

We report here on the design and manufacturing of a SCS to work under conduction cooled conditions. To simulate a cryogen free environment, the tests have been performed in the upper part of the liquid helium cryostat CASPER [8] with the SCS housed in vacuum, to avoid eventual convection cooling generated by the surrounding helium gas.

EXPERIMENTAL SETUP

Conduction Cooled SCS

The SCS is shown in Fig. 1, while the in vacuum housing used for the test at CASPER is reported in Fig. 2. The SCS counts four circuit-branches, made of electrically insulated NbTi superconducting wire VSF-564, manufactured by Supercon, Inc. [9]. All the branches are equipped with heaters, made of resistive, electrically insulated CuMn wire, wrapped around the branches in one layer. The support structure is intended to provide mechanical stability to the branches, to avoid movements during operation. The superconducting wires of the four branches are fed out of the in vacuum housing and connected to a test coil to be placed in liquid helium.

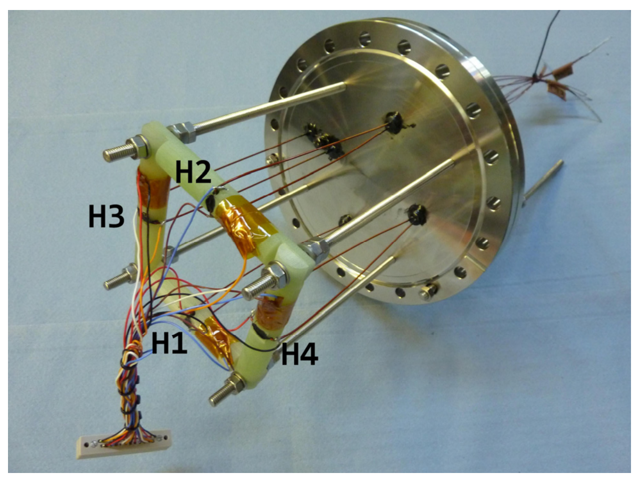

Figure 1: Conduction cooled SCS.

Vacuum Chamber

The top of the chamber is connected to a vacuum pump outside the cryostat. The chamber counts two side-flanges – one of them provides electrical connection between the heaters inside the chamber and the power supply PS2 placed outside the cryostat (see Fig. 3, circuit 2). The chamber is evacuated before the cryostat is filled with liquid helium.

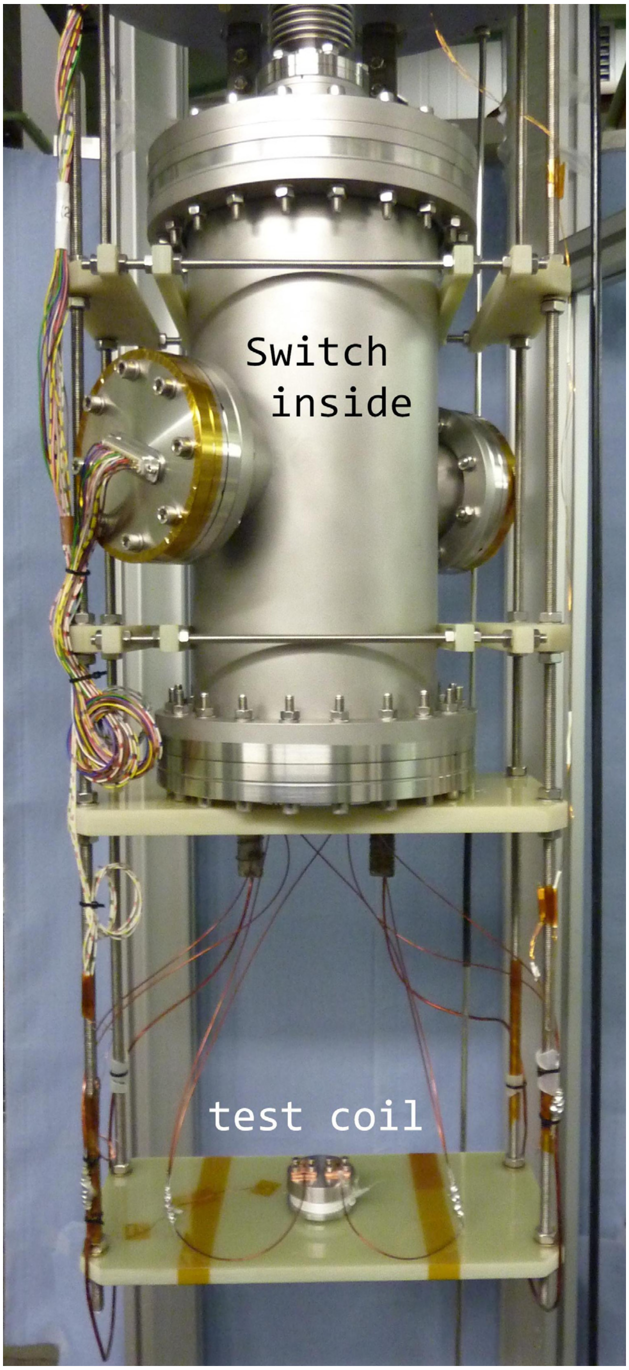

Figure 2: In vacuum housing of the SCS, realized to test its functionality in a cryogen free environment.

Electrical Circuits

A scheme of the measurement setup shown in Fig. 2 is reported in Fig. 3: two electrical circuits are separately powered. Power supply PS1 with maximum output current of 1500 A, powers the superconductive branches of the switch and the test coil, described in section '*Test coil*'. Power supply PS2, a precise current source with maximum output of 3 A, energizes the heaters. In circuit 1, the test coil is soldered to the nodes N1 and N2 of the SCS and the current leads L^+ and L^- of the power supply PS1 to the nodes N3 and N4. The current flow in circuit 1 and thus the current direction in the test coil, described in detail in section 3 is determined by controlling the heaters in circuit 2.

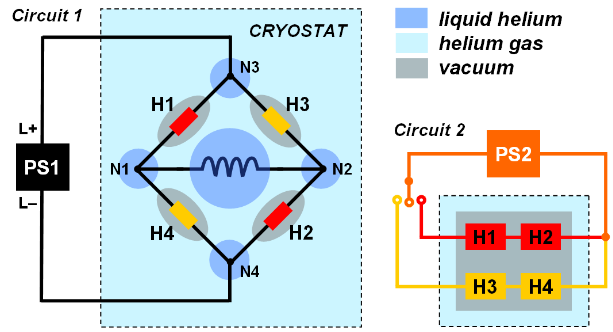

Figure 3: Scheme of the measurement setup showing two electrically separated circuits.

Test Coil

In order to prove the functionality of the SCS, a small test coil has been fabricated and fixed to the (bottom) G10 plate shown in Fig. 2. During the test, the coil is immersed in liquid helium. The coil counts 26 turns and is wound with the same wire that is used for the SCS [9]. The yoke of the coil is made of non-ferromagnetic material. A Hall probe measuring the magnetic field produced by the coil, thus indicating the current direction in the coil itself, is fixed between the yoke and the (bottom) G10 plate. The magnetic field at the place where the Hall probe is fixed is calculated using the finite element method software FEMM [10] and is plotted in Fig. 4 with a red solid line.

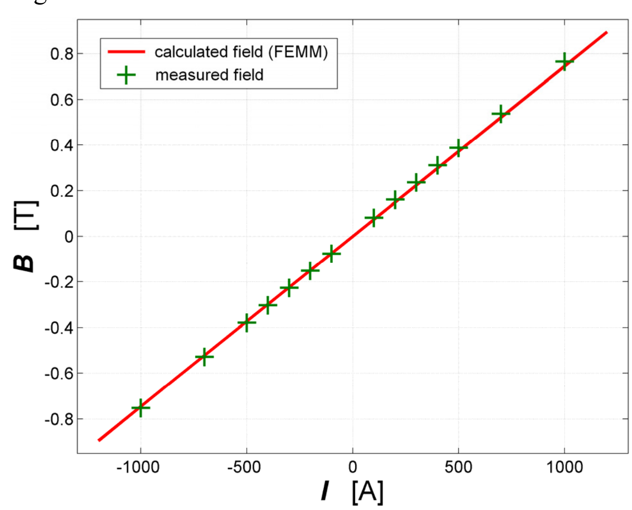

Figure 4: Calculated magnetic field of the test coil where the Hall probe is located (solid red line) and values measured by the probe (green '+' markers).

ISBN 978-3-95450-115-1

SCS OPERATION

The test has been performed in the liquid helium bath cryostat CASPER at ANKA [8]. During the test, the cryogen level is kept approximately 10 cm below the plate on which the vacuum chamber is standing (see Fig. 2). Due to the vacuum maintained inside the vacuum chamber, the heat created by the heaters is mainly transferred by conduction to the branches of the SCS. Depending on the pressure in the vacuum chamber, a small part of the heat will be transferred by convection.

The operation of the SCS is described in Fig. 5, where the current flowing through circuit 1 and the magnetic field produced by the test coil, measured with the Hall probe, versus time are plotted. Figure 5 demonstrates that it is possible to change the direction of the current in the test coil, as shown by the opposite sign of the field measured with the Hall probe, when heating first heater H1 and H2 and then H3 and H4. When H1 and H2 (H3 and H4) are heated, the superconducting wire in the respective branches undergoes to the normal state inhibiting the flow of current between N3 and N2, and N1 and N4 (between N3 and N1, and N2 and N4), and thus, the current path in circuit 1 is as follows: L^+ → N3 → N2 → N1 → N4 → L^- (L^+ → N3 → N1 → N2 → N4 → L^-).

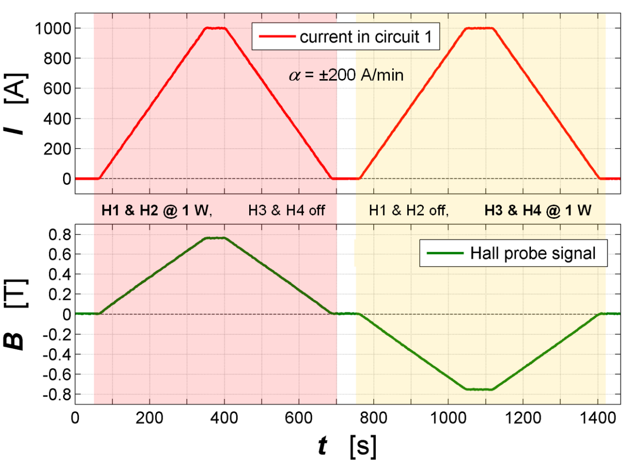

Figure 5: Current of 1000 A flowing through circuit 1 (top) and the field produced by the test coil, measured with the Hall probe (bottom), versus time. During this test a power of 1 W has been applied to the heaters H1 & H2 or H3 & H4.

The current switching was tested at different currents ranging between 100 and 1000 A. In Fig. 5 is shown the case for 1000 A. The same current ramping rate $\alpha = \pm 200$ A/min was kept for all the tests performed. The values of the magnetic field, measured with the Hall probe during the time when the current plateaus are reached (green '+' markers in Fig. 4), are in very good agreement with the ones calculated using FEMM (solid red line).

In addition, we have determined the minimum heater power needed to drive two opposite branches of the SCS (H1 & H2 or H3 & H4 respectively) from the superconducting to the normal conducting state. First, circuit 1 was powered with a current of 100 A, while circuit 2 remained unpowered. In this case, the current was bypassing the test coil – the signal output from the Hall probe before and after powering circuit 1 remained the same. Then, we started gradually to raise the power delivered to the heaters (H1 & H2 or H3 & H4 respectively). The branches underwent into the normal conducting state at a value of 400 mW (200 mW per heater). At this power level, a steep raise of the magnetic field was measured with the Hall probe.

CONCLUSIONS AND OUTLOOK

At ANKA we have designed and manufactured a conduction cooled SCS. Applications to conduction cooled cryogen free insertion devices as the ones under development at ANKA in collaboration with BNG [7] make use of cryocoolers, which have typically a cooling power of 1–1.5 W at 4 K. For this reason, we need for our application a SCS which must not dissipate more than a fraction of a Watt. A first successful test in an ad hoc conduction cooled environment has been performed demonstrating a minimum power dissipation of 200 mW per heater. Even if this would already allow the application of the SCS to a cryogen free ID, we believe that the minimum power level needed for switching can be further reduced by lowering the pressure, and consequently convection cooling, in the in vacuum housing. For this reason the next test is foreseen in a cryogen free environment in the facility CASPER II at ANKA [11].

REFERENCES

[1] S. Prestemon et al, IEEE Trans. on App. Supercond., vol. 16, no. 2, June 2006, pp. 1873 - 1876
[2] B. Kostka et al, *Proceedings of PAC05*, Knoxville, Tennessee, USA (2005)
[3] A. Bernhard et al, *Proceedings of EPAC06*, Edimburgh, Scotland (2006)
[4] A. Grau et al, *IEEE Trans. Appl. Supercond.*, **21** 1596 (2011)
[5] T. Holubek et al, Physics Procedia (in press)
[6] A. Madur et al, Proceedings of FEL 2009, Liverpool, UK
[7] S. Casalbuoni et al, SYNCHROTRON RADIATION NEWS, 14-19 Vol. 24, No. 3, 2011
[8] E. Mashkina et al, Journal of Physics: Conf. Series 97 (2008) 012020
[9] www.supercon-wire.com
[10] http://www.femm.info/wiki/HomePage
[11] A. Grau et al, IEEE Trans. on Appl. Supercond. 2312-2315 Vol. 21-3 (2011)