A NEW SUPERCONDUCTING UNDULATOR FOR THE ANKA SYNCHROTRON LIGHT SOURCE

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Abstract

Superconducting insertion devices (IDs) are very attractive for synchrotron light sources since they allow increasing the flux and/or the photon energy with respect to permanent magnet IDs. Babcock Noell GmbH (BNG) is completing the fabrication of SCU15, a 1.5 m long unit for ANKA at Forschungszentrum Karlsruhe. The period length of the device is 15 mm for a total of 100.5 full periods plus an additional matching period at each end. The key specifications of the system are: a K-value higher than 2 (gap 5 mm) and the capability of withstanding a 4 W beam heat load and a phase error smaller than 3.5 degrees. In addition, during the injection phase of the machine, the nominal gap of 8 mm can be increased up to 25 mm. The magnets are presently being fabricated and will be soon tested in LHe in a vertical cryostat.

This paper describes the technical design of the device and the status of the assembly process with emphasis on the techniques adopted to reduce the influence of manufacturing precision on the performance of the magnet.

INTRODUCTION

SCU15 is a 15 mm period length, 100.5 full periods long undulator with one additional period at each side of the magnet used to adjust the end-field distribution according to the ¾ - ¼ scheme [1]. The specifications of the unit are shown in Table 1. In principle this is an improved version of the existing SCU14 installed in ANKA [2]. In order to reach the specified performance, special attention was given to the cryogenic design and to the manufacturing process [3].

Table 1: SCU 15 Specifications

	Units	Value
Period length	mm	15
Number of full periods		100.5
Max field on axis with 5 mm mag. gap	T	1.5
Max field in the coils	T	2.4
Average current density in the winding	A/mm^2	1000
Minimum magnetic gap	mm	5
Operating magnetic gap	mm	8
Gap at beam injection	mm	25

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CRYOGENIC DESIGN

This magnet has been designed to reach its operating temperature by means of four commercially available cryocoolers, allowing to function in absence of a helium liquefaction plant. The cooling units are capable of providing, all together, a total refrigerating power of 5 W at ~4 K.

Such solution, in order to guarantee the proper operation of the unit, requires a very detailed estimation and analysis of the heat loads on the magnet targeted to the minimization of the gradients between the cryocoolers cold heads and the superconducting coils.

Indeed for an undulator, besides the standard thermal conductive and irradiative heat loads, one has to take into consideration significant additional effects generated by the beam.

In particular synchrotron radiation, resistive wall heating, electron and/or ion bombardment and RF effects, if not actively mitigated, can easily lead to premature quenches of the superconducting magnet [4,5]. The quantification and explanation of these effects is, at the moment, under investigation in several institutes. In particular the ANKA group is an international collaboration in planning a new experiment that shall allow characterizing the beam related heat loads of the machines in which it is installed [6]. The nominal beam heat load for SCU15 operating at ANKA has been estimated to be in the order of 4 W [5].

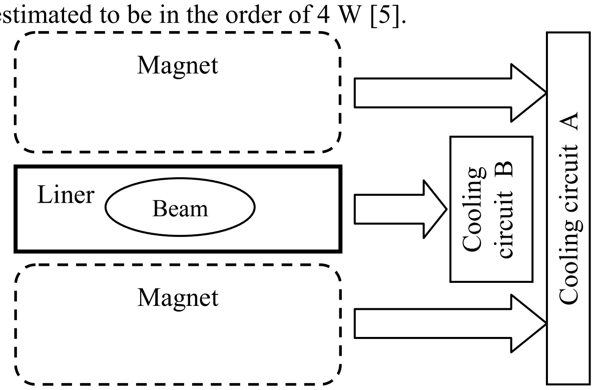

Figure 1: Schematic of the undulator cold mass. The superconducting coils are thermally separated from the liner and are independently cooled.

In order to limit possible increases of the operating temperature in the magnet due to beam heat load, a design based on a concept originally developed for superconducting wigglers at BINP [7] has been adopted. Figure 1 shows the basic principle of this concept consisting in the separation of the cooling circuit of the magnet with respect to the one of the beam pipe (liner).

Surrounding the beam is a 300 µm thick stainless steel non-magnetic vacuum chamber (liner) coated with a 50 µm thick high quality Cu-layer with a RRR higher than 200. In the beam region, the opening of the liner is 7 mm while the magnets are separated by 8 mm. This insulating vacuum layer between the two is kept by means of sixteen Ti-alloy supports designed to maintain a thermal separation along the 1.5 m length magnet with minimal heat load on the superconductor.

Meanwhile the heat generated by the beam in the Cu-layer follows an alternative path through high thermal conductivity copper blocks positioned sideward of the beam. These blocks are directly connected to two of the four available cryocoolers. Such solution allows to maintain the temperature of the superconducting coils below the critical value independently from the heat generated by the beam. Moreover, being separately cooled, the beam pipe can operate at average temperatures higher than 4 K allowing to take advantage of the higher cryocooler efficiency.

ELECTROMAGNETIC DESIGN

The specified maximum magnetic field at the axis of the undulator is 1.5 T corresponding to a calculated maximum field in the superconducting coils in the order of 2.4 T. This field can be reached by a commercially available NbTi wire with specifications shown in table 2.

The expected load line of the magnet compared to the critical surface of the conductor at 4.2 K is shown in Figure 2. The expected operating current of the magnet is 186 A. Such value was exceeded by a 3-periods prototype tested in LHe at ANKA which reached consistently 240 A with a first training quench at 190 A. This prototype allowed qualifying the manufacturing process of the yoke and the performance of the wire in the final configuration. An additional 15-periods undulator prototype was fabricated with test results on the field quality and superconductor performance discussed in [8].

Table 2: Superconducting wire specifications.

	Units	Value
Shape	-	Rectangular
Dimension	mm	0.5 x 0.3
Cu/SC ration	-	1.35
Filament diameter	µm	38
Twist pitch	mm	<30
RRR	-	>65
Ic @ 4.2 K and 4 T	A	212

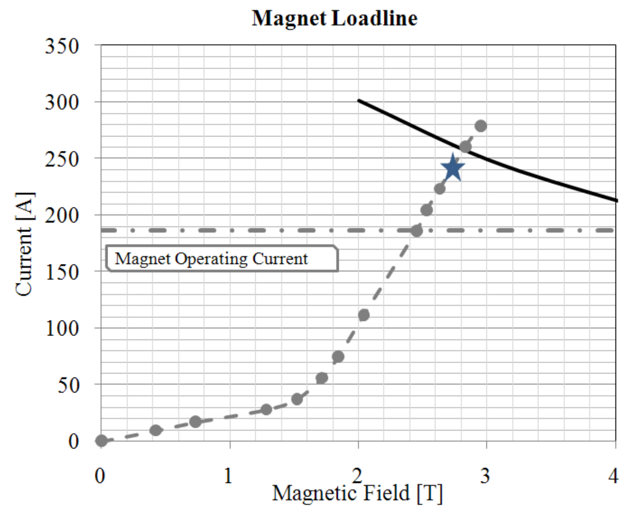

Figure 2: Load line of the magnet. The dashed curve is the load line of the magnet which is iron dominated at low fields. The dot-dashed line represents the operating current of the magnet. The star indicates the maximum operating current of a 3-periods prototype tested in LHe.

YOKE FABRICATION

The magnet has been designed and its manufacturing process has been defined on the basis requirement of maximum 3.5 degrees phase error without local correction. This requirement has been estimated to correspond to a dimensional accuracy of 10 µm for the period length, for the positioning of the winding package and for the pole height [9]. In order to maintain the requested manufacturing accuracy and to reduce the risk during machining, the yoke was not produced out of a single block. Instead it consists of plates stapled together and compressed by two steel rods. While this solution allowed better control on machining accuracy, it introduced additional errors in positioning during the assembly process. In order to keep the final tolerances under control, several measurement steps have been established during the yoke manufacturing process. The results of these measurements are described in the next sections.

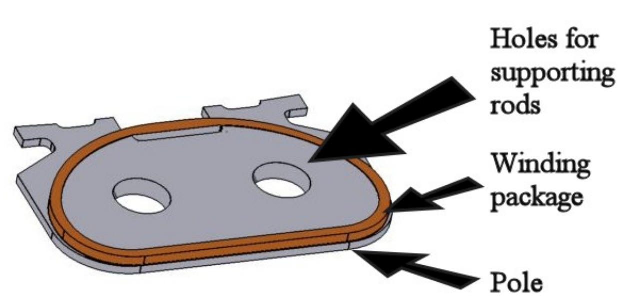

Figure 3: 3D model of one of the 408 plates constituting the two magnet yokes. Each plate includes a pole and a superconducting coil winding.

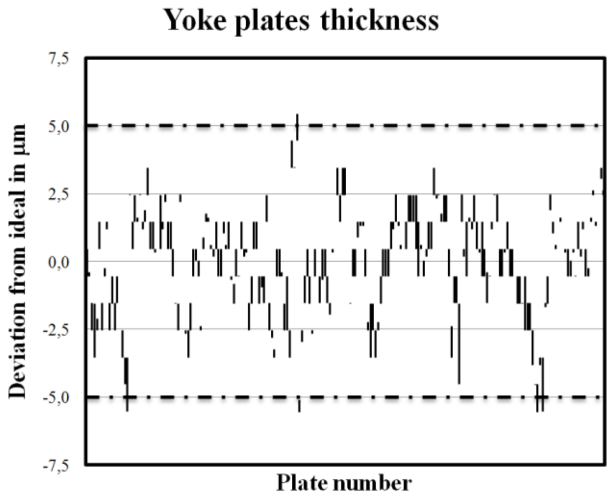

Figure 4: Manufacturing accuracy of 204 yoke plates, on the vertical axis is shown the deviation with respect to the ideal thickness of 7.5 mm.

Period Length

The thickness of the plates, corresponding to half period length of the undulator, has been monitored during several steps of the production process. Figure 4 shows the deviation from the ideal thickness of 204 plates after manufacturing. Before stapling and pressing the plates have been shuffled to minimize the accumulation of the manufacturing inaccuracies. This process is very similar to the "sorting" process performed in PPM undulators. The add-up of the plate thickness inaccuracies on the period positioning is shown in Figure 5.

Winding Positioning

The error in positioning of the winding package is mainly correlated to the dimensional accuracy of the superconducting wire. The coils consist of 7 wires in 13 layers for a total of 91 turns. The dimensional accuracy of each wire has been measured to be in the order of 3 µm leading to a maximum dimensional tolerance on the winding package of ~40 µm.

Pole Height

Within the specified parameters, the flatness of the pole heights is the hardest to achieve since the magnet is close to a slim beam and difficult to handle if not supported by a rigid fixture. The stiffness and manufacturing accuracy of the fixture are the dominating parameter for the flatness of the poles. During the stapling process a maximum bowing of the yoke without stiffening support of ~350 µm along 1.5 m was reached. According to our calculations and simulations this deformation will be removed by the support fixture in the final configuration of the magnet.

CONCLUSION

A new superconducting undulator is being fabricated by Babcock Noell GmbH for ANKA at FZK.

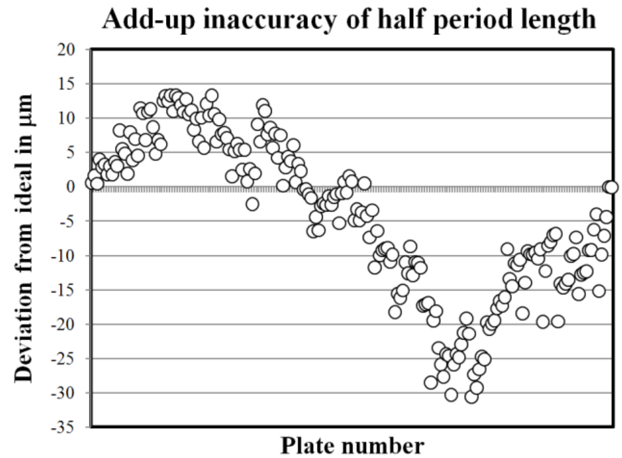

Figure 5: Add-up inaccuracy of the period length after yoke stapling and pressing.

The design phase has been fully completed and, at the moment, after a prototyping phase, the magnet is being fabricated. The manufacturing accuracy of the yokes has been monitored during the fabrication process and the achievements have been discussed in this paper. As soon as the coils will be wound on the yokes, the magnet will be tested in LHe in a vertical Dewar before the integration in the final cryostat which is designed for operation in conduction cooling conditions.

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