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MAGNETIC FIELD INVESTIGATION IN A COMPACT SUPERCONDUCTING UNDULATOR WITH HTS TAPE

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Abstract

The superconducting undulator (SCU) based on the second-generation high-temperature superconducting (HTS) tapes is a promising application for building tabletop free-electron laser (FELs). The short period < 10 mm undulators with a narrow magnetic gap < 4 mm are especially relevant. The advantage of the HTS tape is that it shows both high critical current density and high critical magnetic field. Each tape has 50 µm thickness and 12 mm width and is further scribed by a laser to achieve a meander structure, hence, providing the desired magnetic field pattern.

Thus, a new approach to a superconducting undulator has been presented in the past and is further developed at KIT: each coil is wound with a single 15 m structured HTS tape. As a result, 30 layers of scribed sections lay above each other, and therefore, provide the required magnetic field. The results of the magnetic field measurements together with the results of the numerical investigation will be presented and discussed.

INTRODUCTION

An idea of the undulator using the meander-structured HTS tapes was proposed by Prestemon [1,2]. Figure 1 shows a photo of a second-generation HTS tape with a meander structure, which has been made in-house at KIT using the pulsed YAG laser system at the Institute of Technical Physics (ITeP). The main parameters of the laser-scribed tapes are presented in Table 1 and used later in the computations.

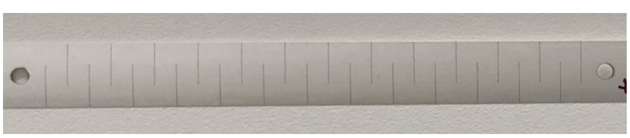

Figure 1: Segment of laser-scribed HTS tape.

Table 1: Main parameters of laser-scribed HTS tapes

Parameter	Value
HTS tape thickness (μm)	55
Period length (mm)	8.05
Period number	12.5
HTS tape groove section (μm mm)	25 4

A concept of a jointless undulator using the structured HTS tapes has been proposed by T. Holubek [3]. The design is the following: a 15 m single-piece of structured HTS tape is folded in half, resulting in the opposing current direction between two layers. Further, two non-magnetic stainless steel yokes are used to wind coils with such tapes, hence, 30 layers of scribed sections lay above each other and provide the needed magnetic field. Figure 2 shows the photo of the undulator prototype based on this winding concept.

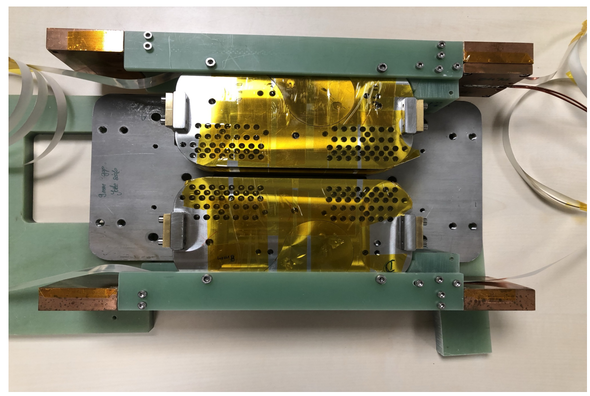

Figure 2: Undulator prototype: structured HTS tape wounded around non-magnetic stainless steel core.

Setup for Magnetic Field Measurements

The magnetic field measurements station CASPER (**Ch**A**r**acterization **S**et-u**P** for Field **E**rror **R**eduction), which was built and installed at our institute and is operated at KARA [4], is shown in Fig. 3. In principle, CASPER is a

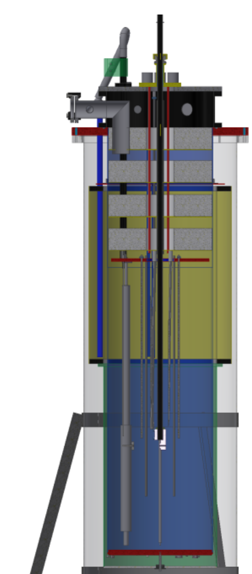

Figure 3: Magnetic field measurements station CASPER I.

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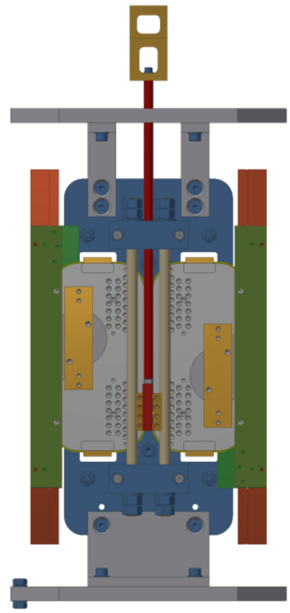

Figure 4: Magnetic field measurement system.

liquid helium bath cryostat that allows to perform magnetic field measurements at 4 K. The maximum current of 1500 A can be achieved through a pair of vapor cooled current leads. In addition, the power supply is provided with a quench detection system. More information on this system can be found in Ref. [4].

In order to place the undulator prototypes inside of the cryostat, a complete new measurement system was designed and fabricated, and is shown in Fig. 4. The magnetic field is measured with an array of ten Hall probes in-house calibrated at KIT at 4.2 K and attached to a sledge. The sledge is later moved by a computer controlled stepper motor.

MAGNETIC FIELD

Measurements

During the experiment, the undulator with the wound structured HTS tapes is vertically submerged into the CASPER I. As previously mentioned, the measurements are conducted at 4 K in liquid helium. The magnetic field generated by the HTS tapes is measured by the array of Hall probes.

Figure 5 shows the mean values of the peaks of the measured magnetic field generated at different current values. As one can notice, the Hall probes at the ends of the array are less affected by the magnetic field. Therefore, in further computations, the Hall probes number 5 – 7 have been used to compare the results as ones, which are (located) in the center of the array.

It is important to mention that these measurements have been conducted with a slightly larger gap between the HTS tapes stacks: 5.6 mm instead of 4 mm. The reason is to protect the Hall probes' array from any possible damage due to the possible shrinking of surrounding parts at 4 K.

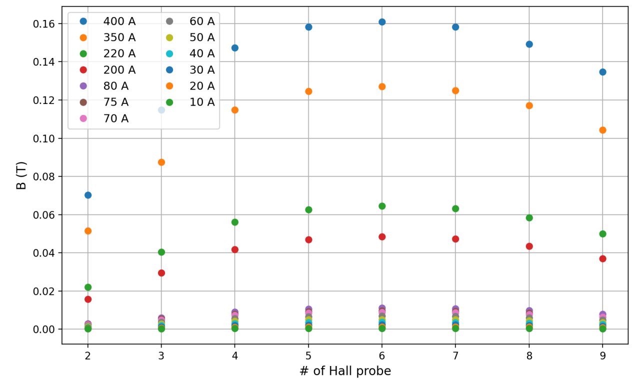

Figure 5: Mean values of peaks of measured magnetic field generated at different current.

Simulations

The magnetic field was simulated using the software Opera 3d (TOSCA solver) [5] and using a Biot-Savart solver written in Python language. Figure 6 shows the model used in the Opera simulations. The magneto-static TOSCA Solver allows to use the so-called Biot-Savart conductors, which do not require meshing, hence, saving time on computations. The model considered the racetrack current path through all the 60 layers of the structured HTS tapes.

Figure 6: Model of the structured HTS tapes used in Opera 3d (TOSCA).

Another tool to compute the magnetic field is a Biot-Savart solver written in Python [6]. This code also considers a simplified model of line currents, which assumes that line currents are sinusoidal. Figure 7 shows the magnetic field along the axis calculated for different current flowing through the tapes. For example, at nominal operating current $I = 500$ A, a peak magnetic field is estimated to be 170 mT.

Figure 8 shows the comparison of the measured and computed magnetic field. As one can notice, the results are in a good agreement. While the Biot-Savart Solver in Python has a straightforward computation of the magnetic field through

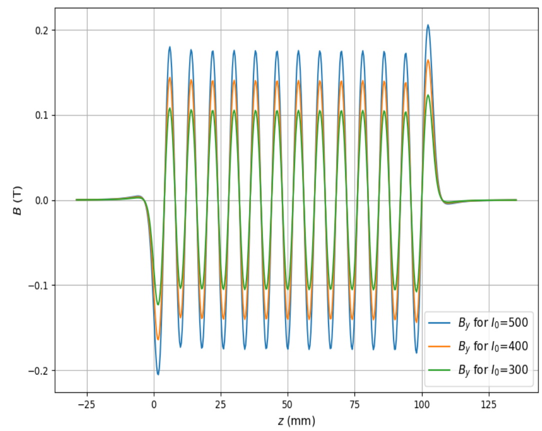

Figure 7: Magnetic field for different applied current, computed with the Biot-Savart Solver written in Python.

the applied current, the Opera computation considers the current density and very dependant on a small change in the model dimensions. The magnetic field at 400 A obtained in the measurements is about 160 mT in comparison to Biot-Savart Solver's ≈140 mT and Opera's ≈170 mT. Here, the results for the middle Hall probe are presented.

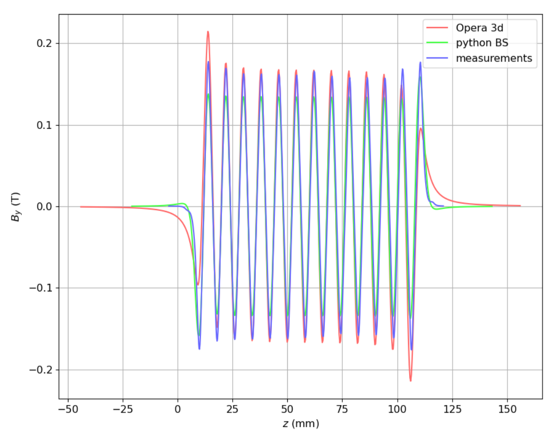

Figure 8: Comparison of the measured and computed magnetic field.

SUMMARY AND OUTLOOK

For the first time, the measurements have been conducted with all the 30 layers of the HTS tapes in each of two stacks in a long run. The first results confirm the principle of such a superconducting undulator using HTS tapes. The critical current at this stage is slightly higher than 400 A, which might be improved. One has to take into account that the HTS tapes are very sensitive to stretching, folding etc.. Also, they are not perfectly homogeneous in terms of carrying critical current [7].

The small differences between the measurements and computations can be explained by both the measurement uncertainties and the numerical errors. In order to converge the results from Opera simulations, the model based on meshing might be used together with the properties of each layer in the HTS tape.

Even though further measurements with the current prototype are planned, the next approach is foreseen - the design with individually structured HTS tape pieces, which are stacked and soldered alternating at the tape ends. For more details see Ref. [6].

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