FIRST MAGNETIC TEST OF A SUPERCONDUCTING NB₃SN WIGGLER MAGNET FOR CLIC

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Abstract

To achieve high luminosity at the collision point of the Compact Linear Collider (CLIC) the normalized horizontal and vertical emittances of the electron and positron beams must be reduced to 500 nm and 4 nm before the beams enter the 1.5 TeV linear accelerators. An effective way to accomplish ultra-low emittances with only small effects on the electron polarization is using damping rings operating at 2.86 GeV equipped with superconducting wiggler magnets. Only superconducting wiggler magnets meet the demanding magnetic specifications of the CLIC damping rings. Although Nb-Ti damping wiggler magnets fulfill the specifications of CLIC, Nb₃Sn wiggler magnets would reach higher magnetic fields leading to even better beam properties for CLIC. Moreover, they have at the same time higher thermal and magnetic margins. Therefore, Nb₃Sn wiggler magnets are under investigation at CERN despite the challenging manufacturing process. This paper presents first results of Nb₃Sn coils and short model tests and outlines the further plans for developing Nb₃Sn wiggler magnets at CERN.

INTRODUCTION

The CLIC damping rings will be utilized to achieve the target emittances in the electron- and positron beams. While the achievable normalized equilibrium emittance improves with shorter period lengths and higher field strengths (Fig. 1 top), the effects of the intra-beam-scattering (IBS) also become more pronounced with short period lengths and strong fields (Fig. 1 bottom). Therefore, a trade-off between the two effects has to be found, taking into account the load-lines of the two conductor-material options Nb-Ti and Nb₃Sn.

Fig. 1 shows that the CLIC specifications can be fulfilled with Nb-Ti. However, with Nb₃Sn the effect of the IBS can be minimized even further. Moreover, Nb₃Sn will be operated at 68% of the critical current compared to 85% in case of Nb-Ti, offering a higher operational and thermal margin to quench. Therefore, the development of Nb₃Sn wiggler magnets was started at CERN and a short wiggler model was manufactured and tested at CERN and KIT. The test results from this Nb₃Sn short model are presented in this paper. The design and system integration of the superconducting CLIC damping wiggler magnets is published in [1].

Figure 1: Equilibrium normalized horizontal emittance γeₓ (top) and the effect of IBS versus the period length λw and versus the amplitude of the sinusoidal magnetic field Bw. The black line indicates the area where the emittance requirements are met. The red and the blue curves show the maximum achievable magnetic flux density for superconducting wiggler magnets with Nb₃Sn and Nb-Ti wire technology, respectively. The dots represent the proposed working points of the wiggler magnets [1].

A Nb₃Sn TEST COIL

Experiments with superconducting insertion devices have shown the importance of a reliable insulation of the wire to avoid eddy currents, inter-strand current loops and resistive heating of the iron body during a quench [2]. The wire used in the short model presented in this paper is a OST RRP wire insulated by S-glass braid. (Bare diameter: 0.81 mm, insulated diameter: 0.94 mm, Sc/Cu ratio: 1.1, No. of filaments: 54 [3]).

As a first step towards a wiggler, a single test coil was manufactured. The iron winding body was insulated by Al₂O₃ ceramic plasma spraying. Since past experiments

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Figure 2: Left: the single test coil. Right: the mechanic clamping structure

Figure 3: Measured quench current (triangles) of the test coil and short sample current (red dots) [7]. The solid red line shows the critical surface at 4.3 K of Nb$_3$Sn and the dashed green line shows the load line of the coil.

Fig. 3 shows the quench currents for the first test and after a thermal cycle. The black line shows the critical surface [5]. The red points show measurement results form a short sample measurement and the black triangles are the quench currents of the coil. The current in the coil reached 85% of the critical current. The coil is operated in the low-field-instability area of the superconducting material. Frequent voltage spikes during ramping (Fig. 4) occur in this area, which in turn can trigger a premature quench. Only a 2% increase of the current could be reached at 1.9 K compared to the current reached at 4.2 K due to magneto-thermal instabilities. Most recent strand development may overcome these limitations [6]. Although, the critical current is not reached, the current reached in the Nb$_3$Sn coil at 4.2 K (1163 A) still surpasses the one reached with a Nb-Ti wire with similar effective cross-section (730 A). Also, the quench current could be repeated with >1100 A over several thermal cycles.

Figure 4: Measured voltage during ramping showing the effect of the instabilities at 4.2 K.

Figure 5: Left: The short model with the top part of the heat-treatment mold. Right: Cross-section of the wire bundle.

THE Nb$_3$SN WIGGLER MODEL

After the encouraging result from the Nb$_3$Sn test coil, a vertical racetrack short model coil with a period length $\lambda_w$ of 40 mm was manufactured using the same techniques. Fig. 5 (left) shows the short model including the part of the heat-treatment mold that applies pressure to the straight wire sections to ensure a straight wire bundle after heat treatment. Due to the shape of the winding body, the plasma spray insulation could not be applied everywhere in the grooves. Instead additional glass fiber was used to insulate the strands towards the iron, achieving a resistivity in the range of MΩ. However, after heat treatment and impregnation this resistivity was reduced to 60 Ω.

In this wiggler configuration the von-Mises stress acting on the coils due to the Lorentz force act mostly compressive. Therefore, a special clamping structure as it was designed for the single test coil is not necessary in this case.

The model was tested in the magnetic measurement setup CASPER at KIT. As discussed in the previous section, instabilities are expected to occur due to magneto-thermal instabilities. Since the total wire length is increased compared to the single coil, the occurrence of instabilities is more likely. Fig. 6 shows the measured voltage during ramping. The quench detection system was at first unable to distinguish between real quenches and these voltage spikes, so the voltage threshold had to be increased, thereby slightly increasing the quench-load. The first three training runs were made with a very low ramp rate of 25 A/minute and quenches occurred at 800 A, 900 A and 920 A (comparison: Nb-Ti current was 730 A). After
OUTLOOK & CONCLUSION

The development of Nb$_3$Sn wiggler magnets will be continued in order to fabricate a second model with a larger period from 40 to about 50 mm, and include in the design additional layers of insulation between the conductor blocks and the poles. In particular, the plan is to increase the thickness of the plasma spray insulation and add a layer of fiberglass over the poles and the winding posts, thus significantly reducing the risk of electrical shorts as observed during the test and in a series of electrical measurements performed after the warm-up. Redesign and optimization of the grooves where the wires transition from one coil to the other and of the current lead area is also in progress.

At the time of the submission of this paper, the drawings of the components used in the first Nb$_3$Sn wiggler model have been reviewed and are in the process of being modified.

The presented tests showed the feasibility of Nb$_3$Sn wiggler magnets with a significantly improved performance over Nb-Ti wiggler magnets. The baseline design for the CLIC damping rings remains Nb-Ti wiggler magnets. A Nb-Ti damping wiggler magnet prototype will be tested in ANKA, Karlsruhe and is under construction with the technical concept presented in [1]. The development of a Nb$_3$Sn wiggler magnet will be continued.

REFERENCES