FIRST MAGNETIC TESTS OF A SUPERCONDUCTING DAMPING WIGGLER FOR THE CLIC DAMPING RINGS

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Abstract

Each of the proposed CLIC electron and positron damping rings will be equipped with 76 wigglers. The length of each wiggler is 2 m, the period length λ 40 to 50 mm, and the beam-stay-clear gap 13 mm. The minimum required mid-plane field B_0 is 2.5 T, that can only be obtained with superconducting technologies. In order to demonstrate the feasibility of such a wiggler, a short model with a period length of 40 mm was built and successfully tested at CERN. The measured mid-plane field was 2 T at 4.2 K and 2.5 T at 1.9 K in the center of a 16 mm gap. The currents were 730 and 910 A, respectively. To fulfill the field specification for the CLIC damping rings at 4.2 K it is planned to replace the Nb-Ti wire with a Nb_3Sn wire.

INTRODUCTION

The damping ring complex will provide positron and electron bunch trains for the Compact Linear Collider (CLIC). Figure 1 shows the obtainable normalized emittance as a function of the wiggler field B_0 and the period length λ. In the calculation damping, quantum excitation and intra-beam scattering (IBS) were taken into account [1]. In each damping ring 76 two-meter-long wigglers will be installed. Figure 1 shows also which normalized emittance can be obtained with permanent-magnet wigglers, superconducting wigglers based on Nb-Ti, and Nb_3Sn technologies. Wigglers with even smaller period lengths and higher fields would allow shortening the CLIC damping rings. The best results can be obtained with Nb_3Sn wires; however, compared to Nb-Ti superconducting wigglers Nb_3Sn superconducting wigglers are more demanding to manufacture. Therefore, the first proof of principle tests were performed with a Nb-Ti wiggler with a period of 40 mm providing a mid-plane field of up to 2.5 T at 1.9 K and a gap of 16 mm. The gap size is determined by the required minimum free aperture of 13 mm required for the incoming beam and the heat load from synchrotron radiation, image currents and other sources generated by the beam. To meet the CLIC specifications also at 4.2 K, Nb_3Sn wigglers are at the moment under investigation at CERN.

The wiggler presented in this paper would meet the requirements of the CLIC damping rings at 1.9 K. A normalized horizontal emittance of 500 nm·rad, a normalized vertical emittance of 5 nm·rad, and a normalized longitudinal emittance of 3957 eVm could be achieved at an energy of 2.86 GeV.

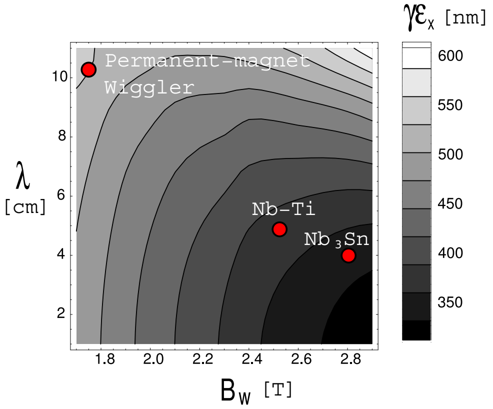

Figure 1: Transverse horizontal equilibrium emittance at fixed wiggler length of 152 m with the effect of IBS [1].

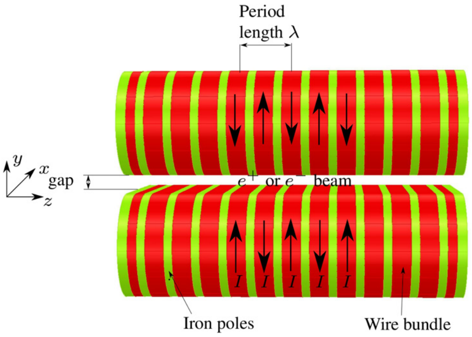

Figure 2: Vertical racetrack wiggler.

SIMULATIONS

Figure 2 depicts the general layout of a vertical racetrack wiggler. Figure 3 shows the load line of the short model. The short sample currents I_{ss} are approximately 730 A and 930 A at 4.2 K and 1.9 K. Figure 4 illustrates the magnetic flux density on the mid-plane in the xz-plane at its operating current at 510 A that corresponds to 70 % of the load line. The first field integral of the short model was minimized by using a coil with half number of windings at the extremities of the wiggler.

Figure 5 shows the equipotential lines through a cross-section in the yz-plane. The Lorentz forces in the wire bundle acts perpendicular to the equipotential lines. There-

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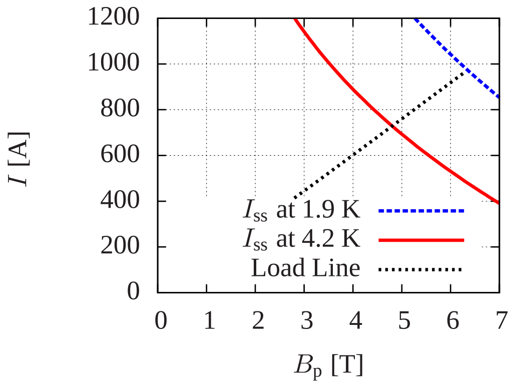

Figure 3: Loadline of the 40-mm-period Nb-Ti wiggler.

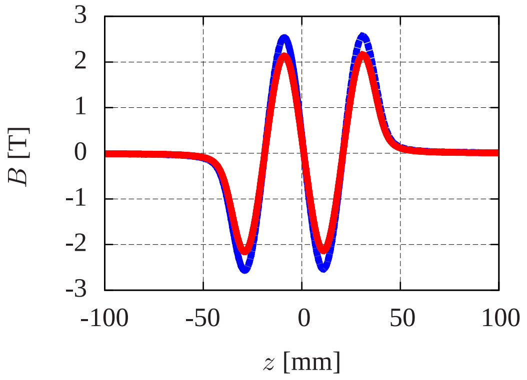

Figure 4: Wiggler's magnetic flux density B at 4.2 K (red) and 1.9 K (blue) for a gap of 16 mm.

fore, the wire bundle will be contracted and has a resulting force, which compresses the wire bundle against the iron yoke. Structural ANSYS 3D and Opera 3D calculations have shown that strain and stress due to Lorentz forces in the coils remain small even without clamping structures. Only the compensating coils at the extremities need reinforcement with stainless steel plates to compensate for their forces.

The stored energy in the short model at the operating current accounts to approximately 1 kJ. Therefore, no special measures for quench protection were necessary.

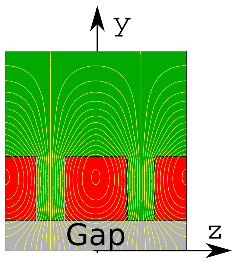

Figure 5: Equipotential lines in the cross section of the wiggler.

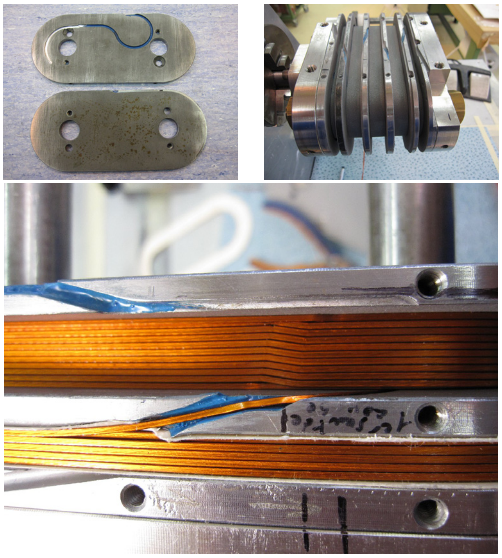

Figure 6: Manufacturing process of short model wiggler.

SHORT MODEL

A $40\,\mathrm{mm}$ period Nb-Ti wiggler model with two periods was designed, built and tested.

Manufacturing

Figure 6 shows some manufacturing steps of the short model. Central post and poles were manufactured separately by using soft iron plates with a thickness of 14 mm and 5.8 mm which were bolted together during the process of winding. The rectangular Nb-Ti LHC corrector superconducting wire #3 (Dimension: $0.73 \times 1.25\,\mathrm{mm}^2$ (insulated), $0.61 \times 1.13\,\mathrm{mm}^2$ (bare), Cu/Sc volume ratio 1.8, filament diameter 6 to $7\ \mu$m) was used [2]. The winding direction has to be reversed after the completion of each winding block to achieve an alternating current direction (see Figure 2). Therefore, the wire was turned through a loop in a groove located in the pole plate. Care was taken to pack the wire bundle as densely as possible to minimize the voids that may result in cracking in the epoxy resin and subsequently quenches. A mold was used to pot the wiggler. The mold compressed the wire bundle and pressed it into the groove to remove all remaining voids in the wire bundle. For electrical insulation 0.11 mm and 0.25 mm thick Nomex® sheets were used (achieved insulation: 127 MΩ at 150 V, 60 s).

Measurement configuration

A magnetic mirror configuration was used to test half of the wiggler as shown in Figure 7. Nine Hall probes were glued on top of the magnetic mirror for the preliminary field measurements.

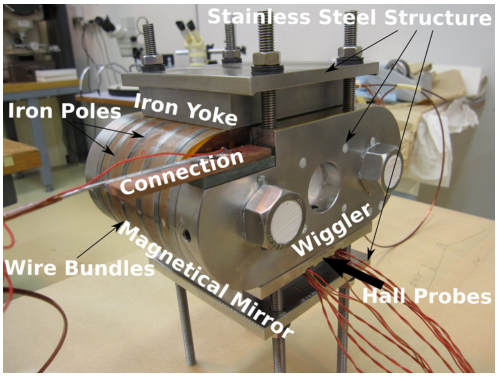

Figure 7: Measurement configuration of wiggler in mirror configuration.

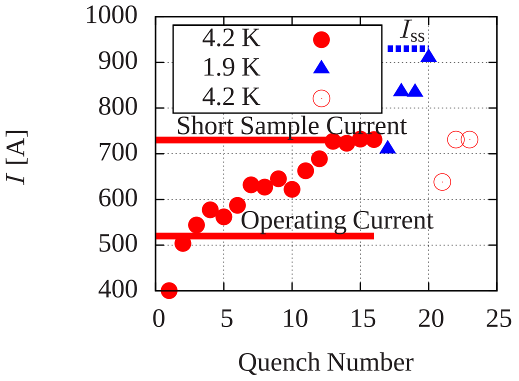

Figure 8: Quench training. First measurement series at 4.2 K (●), second measurement at 1.9 K (▲), third measurement at 4.2 K after thermic cycle to 293 K (○).

Measurements

Figure 8 shows the training characteristic of the wiggler. After 12 quenches the short sample current I_{ss} of 730 A, which corresponds to 730 A/mm^2, was achieved at 4.2 K. After cooling down to 1.9 K, the current could be increased to 910 A, being very close to the expected short sample current. This increase shows the wiggler's mechanical stability. After a thermal cycle to 293 K and cooling down to 4.2 K the same critical current was reached after only one quench.

Figure 9 shows a continuous Hall probe measurement during ramping at a pole at 4.2 K and 1.9 K. At 1.9 K a magnetic flux of 2.42 T was reached.

IMPROVEMENTS

To achieve a mid-plane magnetic flux density exceeding 2.8 T at 4.2 K with the given geometry one has to use advanced superconductors such as Nb_3Sn. Nb_3Sn has a higher critical temperature than Nb-Ti (18.1 K compared to 9.6 K) and a higher critical current despite flux jump instabilities at low fields. A 40-mm-period length Nb_3Sn wiggler has usually a magnetic flux density in the range between 0 and 8 T in the coils. In [3] split solenoid test results are presented, wound with the Ø 0.8 mm Restack Rod Process (RRP) wire of Oxford Instruments (an internal tin process), which we intend to use for the wiggler. These results show that despite flux jump instabilities at low field a current of up to 1200 A can be reached, which corresponds to a current density in the wire bundle of 1200 A/mm^2.

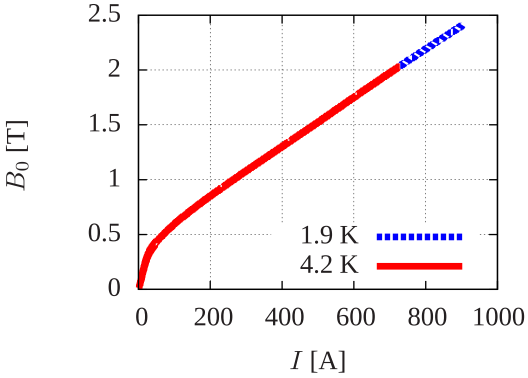

Figure 9: On-axis amplitude magnetic flux density B_0 versus current I.

CONCLUSION

A vertical racetrack wiggler with a period length of 40 mm was designed, manufactured, and tested in mirror configuration. The feasibility of this design concept, which is an essential part of the Compact Linear Collider study, was demonstrated. The wiggler's performance can be boosted by using advanced superconductors such as Nb_3Sn. The manufacturing process is under study at CERN.

ACKNOWLEDGMENTS

The authors want to express their gratitude to J. Mazet and S. Clement, CERN for helping to manufacture the wiggler. Furthermore, the authors would like to convey their thanks to the team of the CERN magnet test facility for conducting the measurements of the wiggler.

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