PREPARATIONS FOR BEAM TESTS OF A CLIC DAMPING WIGGLER PROTOTYPE AT ANKA*

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Abstract

The Compact Linear Collider (CLIC) will require ultra-low emittance electron and positron beams. The targeted emittance will be achieved by radiative damping in the CLIC damping rings. For an efficient damping high-field short-period superconducting damping wigglers will be employed.

In the conceptual design phase of CLIC, the basic layout of these wigglers has been elaborated at CERN. In the course of the CLIC technical feasibility studies, a full-scale damping wiggler prototype will be installed and tested in the ANKA storage ring.

The device is currently under design and construction at the Budker Institute of Nuclear Physics, Russia. Above the magnetic requirements, the main design challenges for the prototype are scalability, particularly of the cooling concept, modularity and the capability of sustaining a high radiative heat load. The experiments at ANKA aim at a validation of the technical concepts applied to meet these requirements. Beyond that an extended experimental program on beam dynamics and alternative technical solutions is envisaged.

This contribution gives an overview over the current status of the project and the further planning.

INTRODUCTION

Following the publication of the CLIC conceptual design report in 2012 [1], an extensive international R&D program on the validation of key technologies required for the realisation of CLIC has started. This CLIC study is focused on the design of a linear e^+-e^--collider with a centre-of-mass-energy of 3 TeV based on the CLIC two-beam acceleration scheme. To achieve the target luminosity of $2 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$, the horizontal, vertical and longitudinal normalised emittance of the beam injected into the main LINAC is required not to exceed $500\,\mathrm{nm\,rad}$, $5\,\mathrm{nm\,rad}$ and $6\,\mathrm{keV\,m}$, respectively.

Damping down the electron and positron beam emittances to these unprecedentedly small values is the task of a complex of damping rings and pre-damping rings. The damping rings, according to the current conceptual design [2], will be compact racetrack synchrotrons with TME arcs and straights equipped with 52 metres of superconducting wigglers each.

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Given the damping ring optics and the total wiggler length, the achievable transverse emittance is the lower, the shorter the wiggler period and the higher the wiggler's flux density amplitude. On the other hand, minimising at the same time the contribution of collective effects to the equilibrium emittance favours wiggler period lengths of 50-60 mm with as high as possible flux density amplitudes [3].

While the target emittances in principle are achievable with state-of-the-art Nb-Ti superconducting wiggler technology, the parameter space accessible for minimising collective effects in the damping rings would be significantly enlarged by employing Nb_3Sn technology.

The R&D on the CLIC damping wigglers, carried out in a collaboration between CERN, KIT and Budker Institute for Nuclear Physics, therefore is following two branches: A conservative approach based on the well-established Nb-Ti superconducting wiggler technology, and an advanced approach employing Nb_3Sn technology. Full scale damping wiggler prototypes of both technologies are planned to be successively tested in the ANKA storage ring.

OBJECTIVES OF THE PROTOTYPE TEST

Currently the test of the Nb-Ti damping wiggler prototype is in preparation. Above a general system and performance test, the main objective of this test is the validation of a cooling concept not so far applied to superconducting wigglers: a cryostat design based on indirect cooling through a thermosiphon flow arrangement was adopted, which was first proposed for the APS superconducting undulator [4].

Indirect cooling was favoured over the standard bath cooling for several reasons: (1) This scheme is less demanding in terms of the mechanical stability of the beam pipe which is not required to sustain an ambient pressure increase in case of a quench; (2) the required helium mass is smaller which is a significant advantage particularly regarding the operation of a large number of wigglers in one cryogenic line supplied by a central cryoplant; (3) the radiative heat load on the beam pipes can directly be extracted by an independent cooling circuit and it might be an option to operate this circuit with liquid Nitrogen; (4) a modular cryostat design is enabled which largely facilitates maintenance and repair of the devices.

The modular cryostat design comes with an additional advantage for the beam tests at ANKA: the wiggler coils and beam pipes are exchangeable and therefore different additional configurations, in particular Nb_3Sn wiggler coils

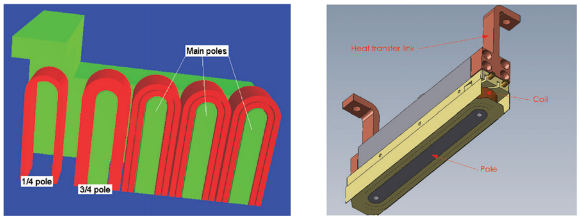

Figure 1: MERMAID model of the wiggler magnet (left); single coil with extended iron core and heat transfer links (right) [5].

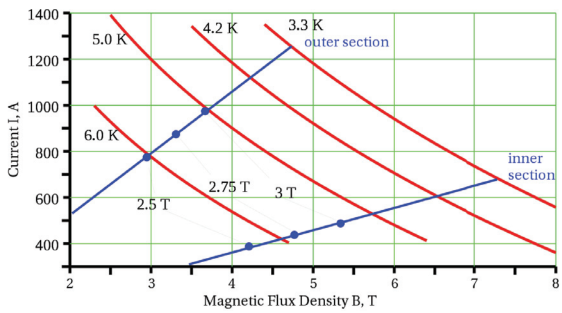

Figure 2: Load lines of the inner and outer coil sections (blue) and critical current as function of B and T (red).

and alternative beam pipe shapes and surface coatings may be investigated in the second project step.

The validation of the CLIC damping wiggler cooling concept at ANKA will cover a long-term reliability test under normal operation conditions of the ANKA storage ring as well as special tests under operation conditions representative for the CLIC damping rings.

These conditions in the first instance will be characterised by the synchrotron radiation generated by the wigglers which will result in a significant radiative heat load on the cold bore beam vacuum chambers of the wigglers. This heat load, integrated over the surface of the beam vacuum chamber, is expected to reach up to 40 W [3]. During the beam tests at ANKA, these conditions will be simulated using additional resistive heaters placed at the downstream end of the beam vacuum chamber.

MAGNETIC AND CRYOGENIC DESIGN OF THE PROTOTYPE

The damping wiggler prototype employs a state-of-the art Nb-Ti horizontal racetrack coil design as sketched in Fig. 1. The basic characteristic parameters of the magnet are listed in Table 1. The main coils consist of two sections. The outer sections will be operated at about twice as high current than the inner sections close to the iron poles, thus maximising the number of Ampère-turns. The load lines for the two coil sections are shown in Fig. 2. For cooling the coils, their iron cores, extended on the back side, will

Table 1: Magnetic Design Parameters of the Prototype

Basic parameters	
λ_w	51 mm
magn. gap [mm]	18 mm
$\tilde{B}_y$	3 T
I/I_c on load line @ $T = 4.2\,\mathrm{K}$	86%
T_{quench} @ $\tilde{B}_y = 3\,\mathrm{T}$	4.8 K
main poles	68
Wire parameters	
Diameter (bare)	0.85 mm
Nb-Ti:Cu	1.1
Filaments	312

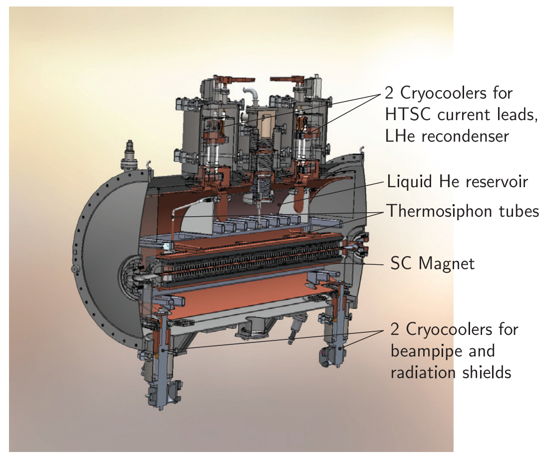

Figure 3: Cross section of the CLIC damping wiggler prototype [5].

be thermally connected with copper links (cf. Fig. 1, right part) to a copper plate extended over the whole coil array. This plate will be cooled through two thermosiphon pipes (top coil array) or through copper braid links to the upper copper plate (bottom coil array).

Figure 3 shows a cross-section of the complete cryostat. The thermosiphon tubes cooling the upper copper plate are connected to an internal liquid Helium reservoir. The Helium will be recondensed by two cryocoolers (Sumitomo SRDK-415D), providing zero boil-off and a Helium temperature of $\lesssim 4\,\mathrm{K}$ under normal operation conditions. The first stages of these cryocoolers will be used to cool the HTSC current leads.

For cooling the beam pipe and the radiation shields, two further cryocoolers (Sumitomo SRDK-408S2) will be used. Under the heat load at regular operation in the ANKA storage ring ($< 4\,\mathrm{W}$) the beam pipe temperature will be 10 K. With the 40 W heat load expected in the CLIC damping rings, the beam pipe temperature will not exceed 30 K.

Finite element simulations (cf. Fig. 4) have shown that superconducting coils and beam pipe will be effectively thermally decoupled. Even at a beam pipe temperature of 70 K the temperature gradient over the coil array is ex-

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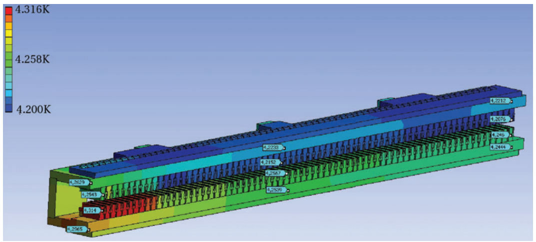

Figure 4: Worst-case estimation of the temperature distribution over the coil arrays of the wiggler assuming that the thermosiphon tubes provide a heat sink at a fixed temperature of 4.2 K and that the first 0.5 m of the beam pipe have a uniform temperature of 70 K and the emissivity of a black body. The maximum temperature at the coil arrays is 4.32 K.

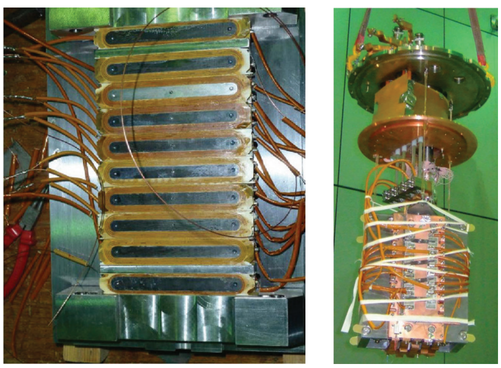

Figure 5: Short model coil assembly (left) and experimental setup for quench and cooling performance test (right).

pected not to exceed 0.15 K.

The cryostat design is fully modular and optimised for an easy access to the cold mass.

SHORT MODEL TESTS

The indirect cooling scheme and the magnetic performance were tested on a ten-pole short model magnet. Fig. 5 shows the coil assembly of one half of the short model and the set-up prepared for the installation in a test cryostat recipient. The short model including thermal links, cooling plate, spacers and soft magnetic housing was fully representative for the full-scale magnet except for the splices interconnecting the coils which were soldered instead of cold-welded.

The cooling plate of the coil assembly representing the upper half of the wiggler magnet was directly connected to the second stage of a cryocooler with 1 W cooling capacity at 4.2 K. That of the coil assembly representing the lower half was connected to the "upper" half through copper straps.

Table 2 summarises the quench history of the short model magnet. In steady state operation, the temperatures measured at the pole faces did not exceed 3.8 K, the temperature difference between "upper" and "lower" half was lower than 0.1 K. The first quench occurred at 459 A (inner section),1097 A (outer section) at 3.7 K, which is about 90% of the critical current on the load line. The target medial plane magnetic flux density amplitude (3 T) was reached already at this quench.

Table 2: Quench History of the Short Model (Excerpt)

#	I_{inner} [A]	I_{outer} [A]	$\tilde{B}_y$ [T]	$T_{\max}$ [K]
1	550	1097	3.314	3.70
5	484	968	3.000	4.83
6	387	773	2.500	5.75
7	436	872	2.750	5.33

Quenches 5-7 were triggered by increasing the temperature at fixed current corresponding medial plane flux density amplitudes of 3, 2.75, 2.5 T, respectively. This test showed that the wiggler could be operated at the target magnetic flux density amplitude up to a temperature level of 4.8 K.

The short model test, combined with the thermal model calculations for the full-scale wiggler, provided confidence that the cooling concept for the prototype is feasible.

PROJECT STATUS AND FUTURE PLANS

The full-scale magnet and cryostat are currently being manufactured at the Budker Institute, Novosibirsk. The delivery to ANKA is planned for spring 2014.

In parallel the research on the winding and processing of Nb_3Sn wiggler coils is continued at CERN [6]. Beam dynamic simulations implementing a realistic model of the CLIC damping wiggler prototype in *ELEGANT* are under way for preparing the experiments at ANKA and as a step towards refining the beam dynamics simulations for the CLIC damping rings.

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