Swiss Accelerator Research and Technology

PSI
HTS Bulk Undulator

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This project has the ambition to demonstrate a new undulator technology with much higher brightness than today status of the art CPMUs[1]. It will potentially push the community to equip the hard X-Ray beamlines of the new Diffraction Limited Storage Rings and future Compact FELs with this new technology on a world-wide impact, as it was the case first for in vacuum undulators. The success of this prototype will require a technology transfer to profit from the expected favourable business case. HTSUs[2] will not only improve and speed up existing activities at the beamlines but they will allow new experiments in medium energy storage rings today possible only in the few large existing facilities, like APS[3], SPring-8[4], ESRF[5] and PETRA III[6].

An example of the application of HTSUs is the technique of total scattering in material science, where a high scattering vector Q is required. With higher photon energies now accessible with an HTSU (40-100 keV), is possible to get large $Q = 4\pi / \lambda \sin \theta$ with relatively small maximum angles (40-60°) and use a frontal area detector for rapid data acquisition. In the medium energy range (20-30 keV) presently it is possible to use a 1D detector, with angles larger than 120°, with slow acquisition times but excellent resolution. With the higher flux of the HTSU both at medium and high photon energies, it will be possible to do much faster 1D high-angle acquisitions and even faster acquisitions with frontal 2D. A second high-profile example is undulator-based tomography of high-Z material with dimensions of the order of a few millimetres, where high photon energies and high flux density are required to get through samples of the same order of magnitude linear dimensions. In addition, phase-contrast tomography is required for fast tomography in the 10-100 Hz tomogram rate, which can only be provided by the relatively high coherent fraction offered by undulators. In the following, the status of the project is reported.

1. Context

This project is dedicated to the development of a High Temperature Superconducting (HTS) undulator, utilising REBCO bulks, and adhering to the design proposed by Kii and co-workers [1,2]. To ensure clarity, the device is delineated into three primary components: the HTS insert, the 12T Nb_3Sn solenoid, and the cryostat, see Fig.1. At the heart of the undulator lies the HTS insert, comprising a meter-long staggered array of REBCO bulks. A modular design based on Cu-REBCO disks is employed to mitigate high tensile stress in the superconductor, facilitate precise assembly, and optimise the magnetic field profile by enabling adjustment of the bulks' relative positions along the array. The 1.2-meter 12T horizontal solenoid serves to magnetise the bulks, thereby generating the requisite undulator field within the vertical gap between the upper and lower rows of bulks. Additionally, the cryostat plays a crucial role, enabling

[1] Cryogenics Permanent Magnet Undulators.
[2] High Temperature Superconducting Undulators.
[3] Advanced Photon Source, Lemont, IL 60439 USA.
[4] Super Photon Ring – 8 GeV, Hyogo 679-5198 Japan.
[5] European Synchrotron Radiation Facility, 38043 Grenoble Cedex 9.
[6] At DESY (Deutsches Elektronen-Synchrotron), Hamburg, Germany.

independent cooling and temperature control of both the insert and the solenoid, while also facilitating the powering of the solenoid. The inception of the research and development efforts commenced with the design of the insert, followed by meticulous assembly and rigorous testing of eleven 10-cm-long prototypes (also referred as short-prototypes). These tests were conducted under cryogenic conditions, ranging from 20 K down to 7 K, utilising the 12 T-solenoid-facility of our partners at the University of Cambridge.

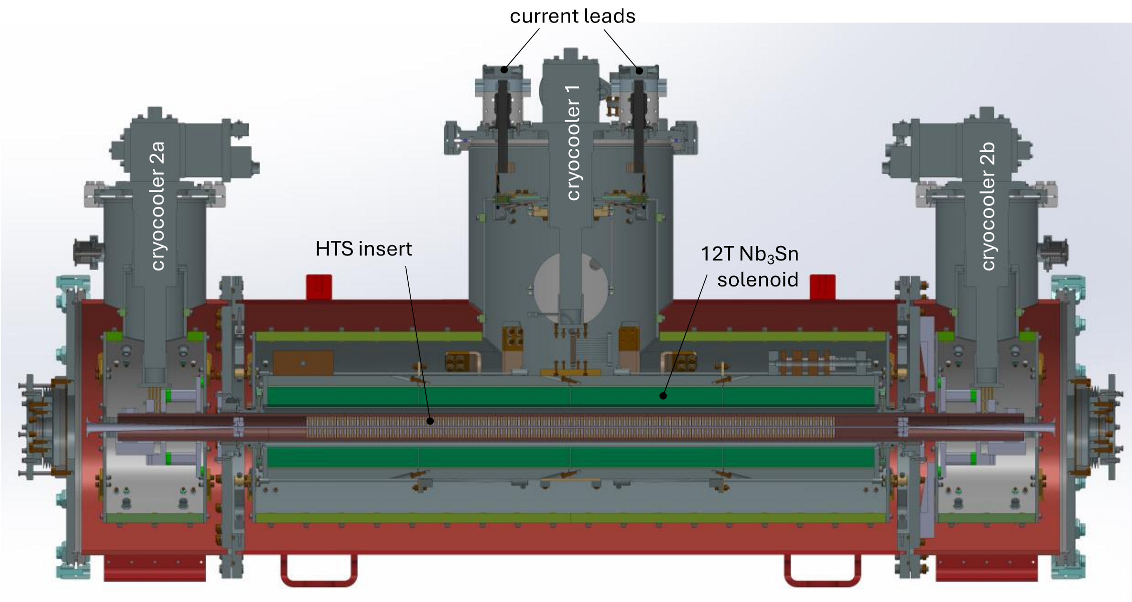

Figure 1 A cutaway view of the meter-long prototypes showcasing the main components: the HTS insert, the 12T Nb_3Sn solenoid, and the complete cryostat featuring cryocoolers, current leads, thermal screen, and the vacuum vessel (in red).

2. Status of the project

The short-prototype program has achieved significant milestones, including assessments of various REBCO bulks (Y, Gd, Eu) from three different manufacturers. Initial exploration with second-generation (2G) HTS tape stacks was abandoned due to inferior performance in strength and homogeneity. In bulk sample evaluation, sorting algorithms were explored [3] alongside assessments of different ferromagnetic pole/shim materials (FeCo, Ho). Demonstrations showcased a record field of 2.1T at 10K over a 10mm period length and 4.0mm magnetic gap using GdBCO bulks [4], see Fig.2. Subsequently, the same components were used to assemble and successfully test a helical undulator [5], marking the first successful application of this technology in a geometry advantageous for Free Electron Lasers.

The bulk manufacturer CAN-SUPERCONDUCTOR (Czech Republic) was selected for their exceptional balance of quality and price, utilising their innovative Single Direction Melted Growth (SDMG) technique [6] to significantly improve bulk homogeneity and reduce costs, notably cutting growth time by over fivefold. A significant milestone was reached with the order of 250 Cu-GdBCO-SDMG disks crucial for the construction of the meter-long prototype. Bulk production is complete, and the disks are undergoing machining, embedding in the copper matrix, and measurements in liquid nitrogen (LN2), with delivery expected in March 2024. Progress on the HTS insert assembly design remains on schedule, with procurement processes for necessary components underway. Additionally, a custom galvanic-formed elliptical vacuum chamber (7Hx4Vmm internal) has been crafted by Galvano-T, featuring various wall thicknesses (0.10, 0.15, 0.20mm), with ongoing vacuum testing and roughness measurements.

Procurement has been finalised for the cryostat (Fig.3), HTS current leads, cryocoolers with compressors, and power supply. However, challenges in manufacturing the Nb_3Sn 12T solenoid at Fermilab have resulted in delays, with issues in the impregnation procedure following winding and heat treatment necessitating tooling redesign, leading to an additional six-month delay (from March to September 2024). The first cryogenic test of the prototype will be conducted in the first quarter of 2025 and its installation in the new storage ring of the Swiss Light Source is planned for 2026.

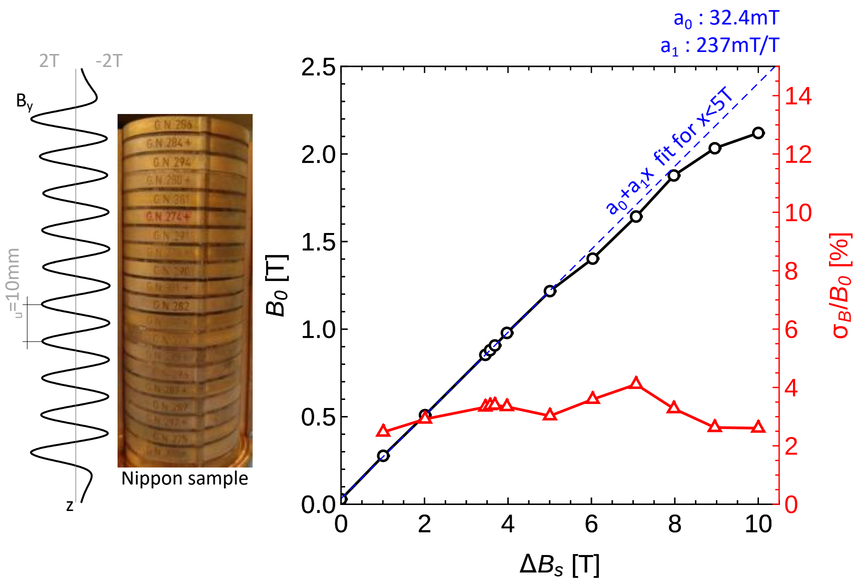

Figure 2 The undulator magnetic field amplitude B_0 measured on a short prototype made of GdBCO bulks from Nippon Steel. A strength higher than 2T was recorded on a 10mm period length and 4mm magnetic gap.

Figure 3 The vacuum vessel at the Fermi National Laboratory.

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