Magnetic Field Optimisation for HTS Staggered Array Undulator Samples

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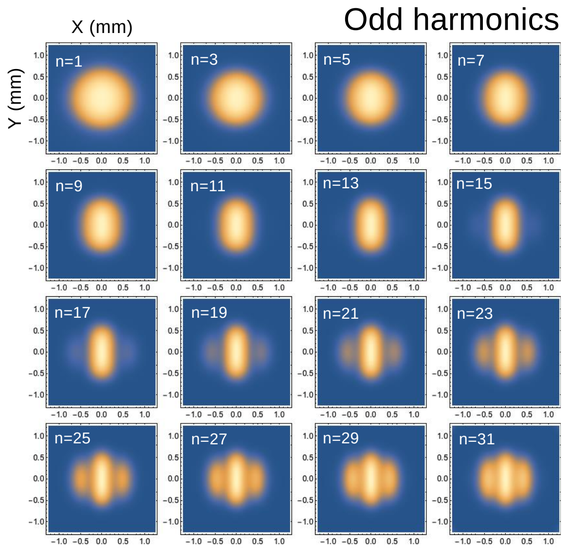
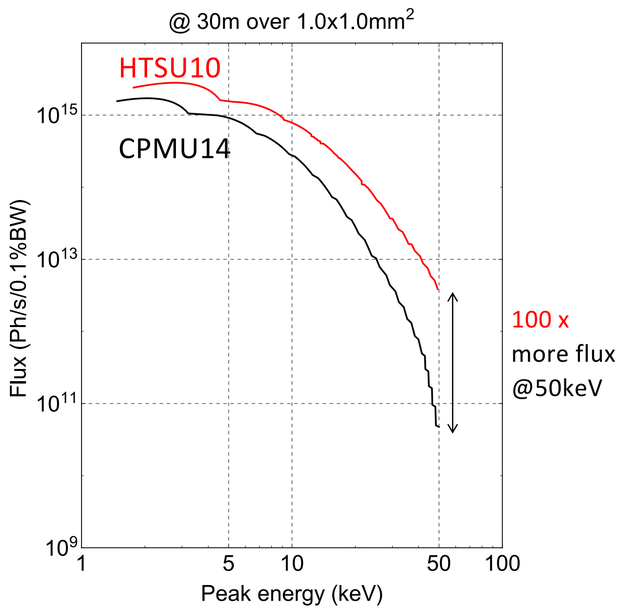
Abstract - A high-temperature superconducting (HTS) undulator is under development at the Paul Scherrer Institut. This device equipped with HTS bulks is a novel technology to generate short period and high strength magnetic field. For medium-energy synchrotron storage rings, this is a promising option to increase tremendously the photon flux in hard x-ray domain. The experiment for a sample consisting of 20 HTS bulks gave an encouraging result above 1.9 T magnetic field of 10-mm period at 4-mm magnetic gap. Nevertheless, the peak-to-peak fields are not homogeneous enough to ensure the corresponding photon beam quality. A magnetic optimisation method of sorting and shimming is presented together with the simulation of the resulting optimized field.

I-TOMCAT beamline of SLS 2.0



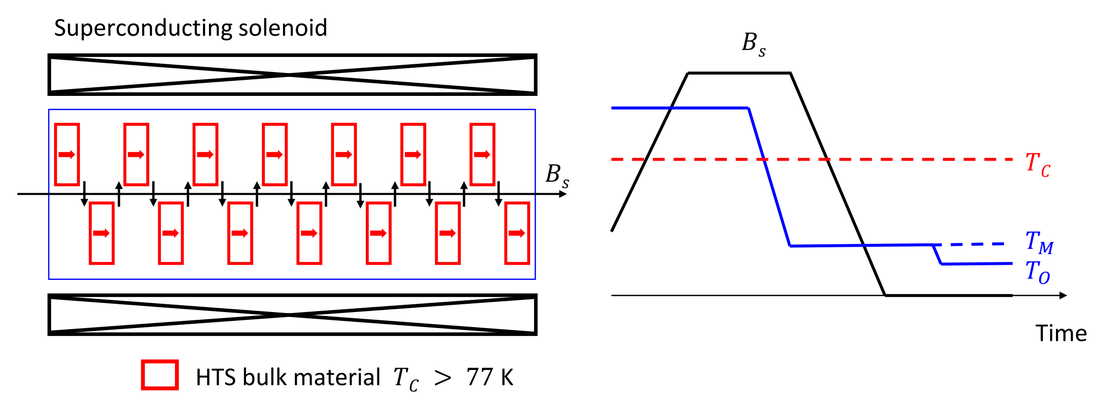
Calculations for the future I-TOMCAT beamline, dedicated to tomographic microscopy, flux at 30 m from the source to illuminate a sample of about 1 mm²



CPMU, $\lambda_u = 14$ mm with $B_0 = 1.3$ T

Shorter period and higher field:
HTSU, $\lambda_u = 10$ mm with $B_0 = 2.0$ T

HTS Staggered Array Undulator and Field-Cooling Magnetisation

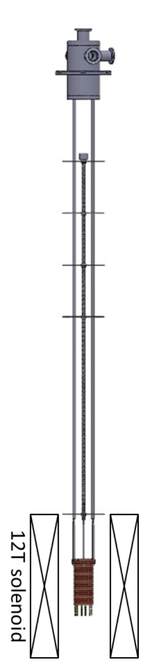


- The solenoid generates 8 / 10 T field along longitudinal direction.
- Cooling down the temperature to 10 K (below critical temperature).
- Ramping down the solenoid field B_s to zero. The field-drop induces a persistent eddy current in the HTS bulks thus the bulks are magnetized.
- Operation temperature < 8 K to freeze the flux creeping (τ > 3 years)

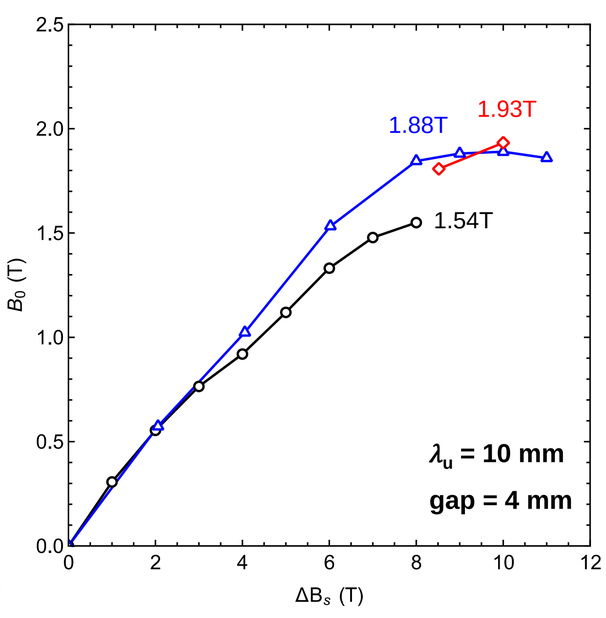
The Short Sample Program and Measurement results

a) Cambridge GdBCO sample. b) ATZ YBCO + Cobalt-Iron poles, first industrial short sample. The HTS crystals are embedded (shrink-fit) into a copper matrix with micro-meter level accuracy, to be mechanically and thermally stabilised. An additional Aluminium shrinking cylinder is used to precisely assemble the undulator array.

Experiments in collaboration with University of Cambridge



A high field of **1.93 T** was recorded, which has a factor of 2 compared with the CPMU of the same undulator period and magnetic gap.



○ Cambridge GdBCO / FC 8T

△ ATZ YBCO + Co-Fe / FC 8T

◇ ATZ YBCO + Co-Fe / FC 10T

Upcoming samples

CAN* GdBCO w/wo CoFe

CAN* EuBCO w/wo CoFe

NS** GdBCO w/wo CoFe

...

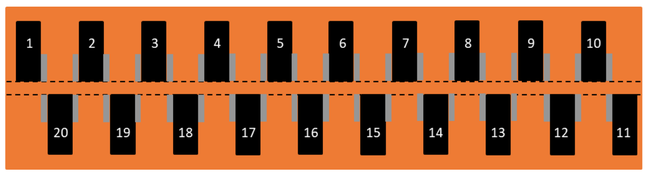
**CAN-SUPERCONDUCTORS*

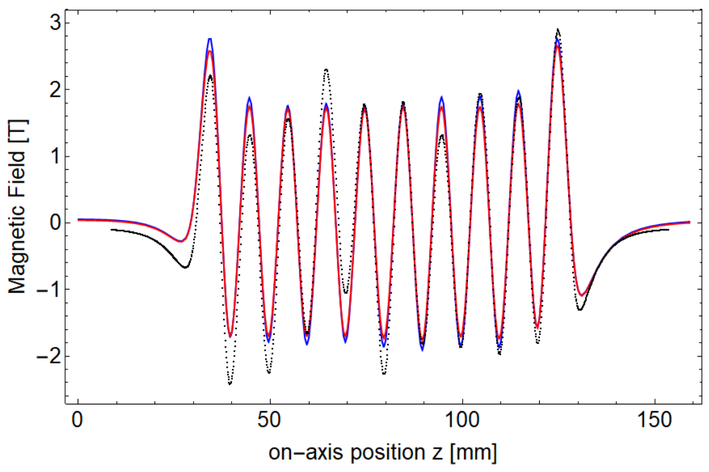
***Nippon Steel Co.*

B_0 is the on-axis undulator field

ΔB are the (-) changes in the background solenoidal field

Magnetic field optimisation



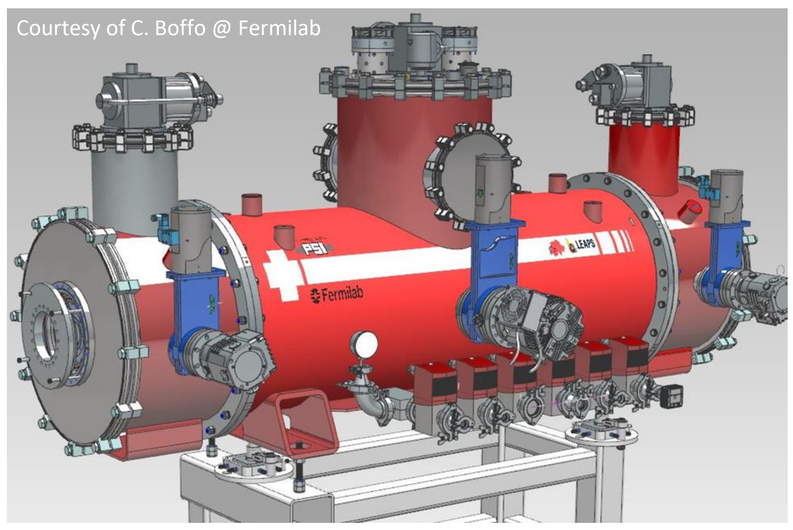


We developed an inverse analysis method to estimate the critical current density (J_c) of each bulk from the measured field. After disassembly, sorting and reassembly, the magnetic field quality improves. The number here represents the order the J_c factors.

- Measurement data
- After virtual sorting
- With virtual pole-height shimming

- The RMS phase error decreases from more than **100** ° to **3.7** ° in the simulation performed with Ansys
- Dipole field correcting coil is required with this optimisation method
- The experiment and test will be in this summer together with the feasibility studies about the reproducibility of the magnetisation process,

Towards Meter Long Prototype



- Superconducting solenoid
- Cryocoolers:
  HTS temperature: ~ 10 K
  LTS temperature: 4.0 K
- Vacuum vessel
- Contract with Fermilab for cryostat with Nb_3Sn solenoid
- Technical design (including 2D drawings) completed
- Assembling starts in September 2022

Magnetic length	Total length	Period length	Magnetic gap	Target K value
1 m	~ 1.8 m	10 mm	4 mm	2

Summary and outlook

- The first industrial bulk HTS undulator model is fabricated with new machining and assembling techniques and obtains a mean peak field of up to 1.92 T at 10-mm period and 4-mm magnetic. Higher field is promising with better magnetic design, superconducting material and pole material. More short samples will be measured to analyse the reproducibility of magnetisation as well as select the provider of the superconductors. Quality control (pre-sorting) at the production site has a key impact. Field quality (peak to peak variation) less than 5% shall be achieved to allow a fine magnetic field optimisation to reach a acceptable RMS phase error. Sorting and pole height shimming test in series will be carried out soon during the following months. Eventually, the design details of the Meter Long Prototype is under discussion, the purchase and fabrication of the key components are on going, the delivery is scheduled in June 2023,

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