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Thermal calculation and testing of SLS 2.0 crotch absorbers

MEDSI 2023, November 6-10, 2023, Beijing, China

Contents

- Introduction
- Water cooling modelling
- Prototype thermal test and calculation
- Absorber thermal mechanical calculation
- Summary

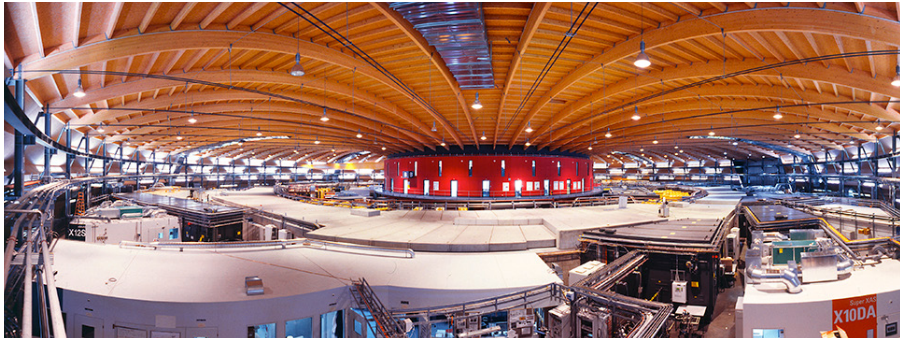
Swiss Light Source Upgrade Project: SLS 2.0

SLS 1.0:

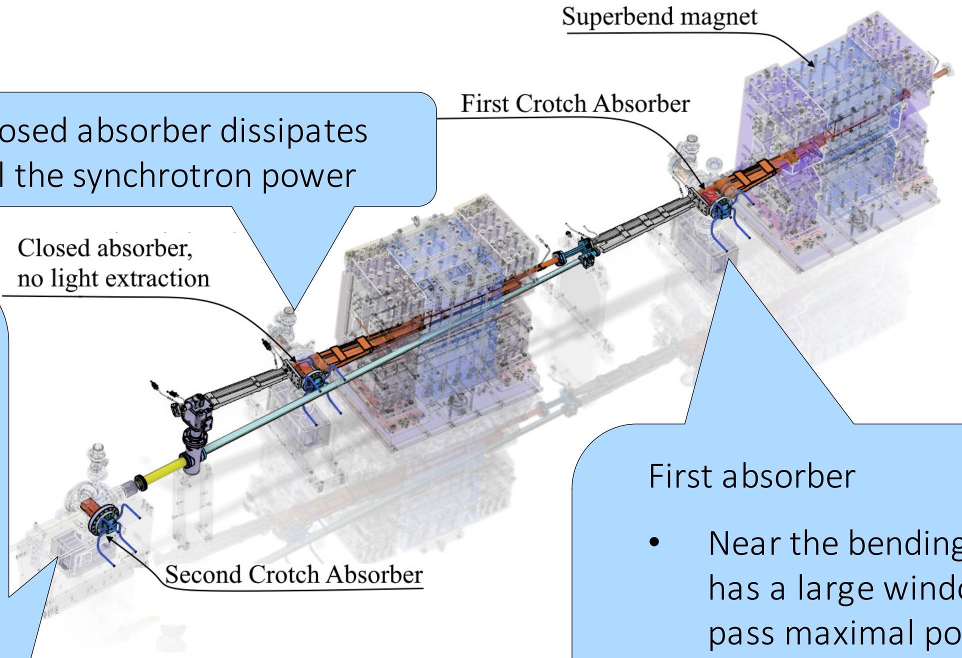
- 3rd generation synchrotron light source
- User operation since 2001
- Last beam on Sept. 30, 2023

SLS 2.0:

- 1st beam Jan. 2025
- New storage ring: >40x higher hard X-ray brilliance
- low-emittance magnet lattice and beam pipes with a smaller aperture



Three types of absorbers



Closed absorber dissipates all the synchrotron power

Second absorber

- at the Front Ends entrance.
- precisely match the beam requirements
- protect the optics components
- dissipate the residual heat from the first absorber

First absorber

- Near the bending magnets. It has a large window opening to pass maximal possible beam size while protecting downstream chamber
- It dissipates most of the power

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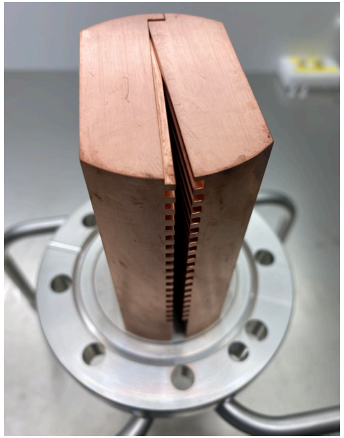
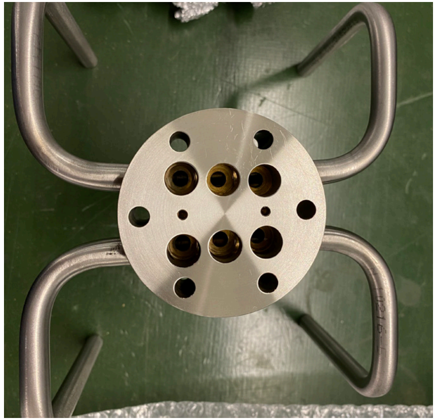
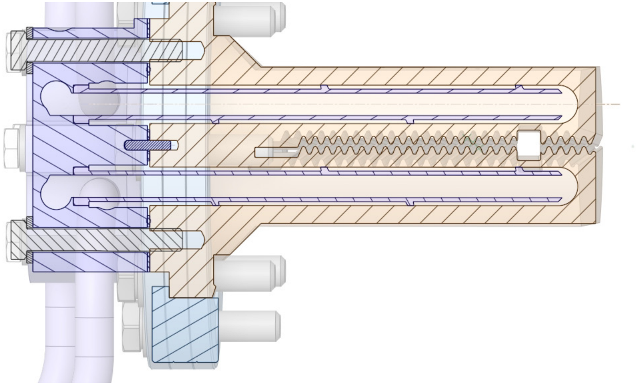
Water cooling modelling





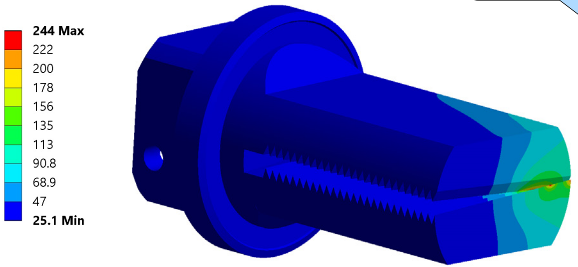


- Two water-cooled, toothed jaws
- Made of Glidcop
- 6 water channels
- Dissipates a maximum heat power of 6 kW

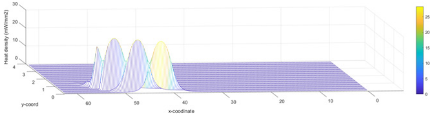
Water cooling modelling

- ANSYS mechanical thermal model as forced convection
- Fluent CFD conjugate heat transfer (CHT) simulation

Thermal submodelling



Adiabetic boundary condition

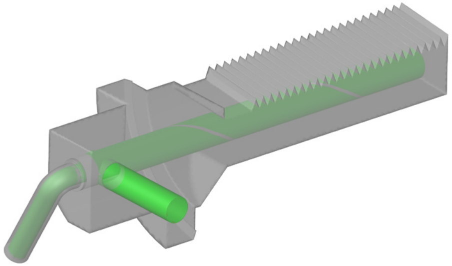


Power density distribution as from SYNRAD calculation

Convective boundary condition to maintain the same power transport by water as in the global model

Constant Power density

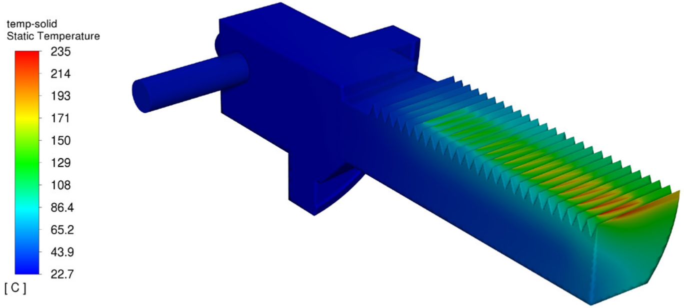
CHT vs. Thermal model



Fluent model including absorber, water pipe and water

Inlet water temperature 25 °C and velocity 1.5 m/s

The turbulence model SST k-omega



Fluent CHT model, max. T = 235 °C

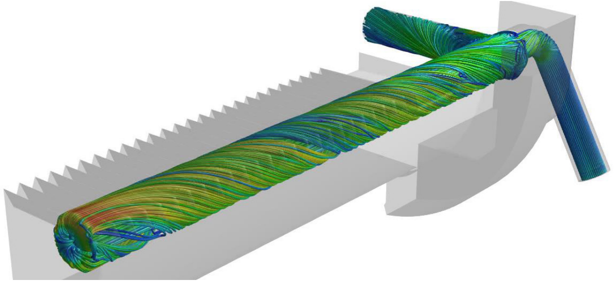
Outlet water T= 30.3 °C

thermal model, max. T=242 °C

Outlet water T= 30.3 °C

Heat transfer coefficient 15 kW/(m^{2}K)

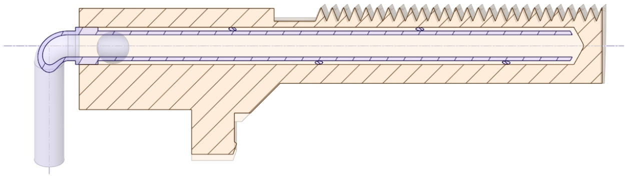
Cooling channel modification



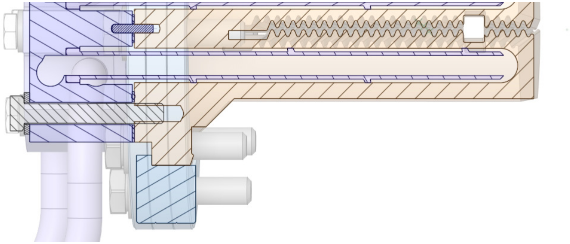
Max. water velocity 3.5 m/s

Swirl flow after entering the helical channel

Conical shape



Spherical shape



Intergrated water guide

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Prototype Absorber – Thermal test

Thermal test in e-beam welding chamber

Test conditions

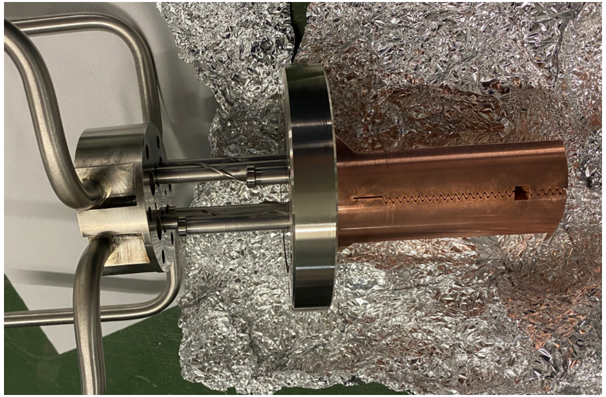
- Controlled water flow rate and heat power
- Water T measured at individuell in- and outlet
- Absorber T measured at 6 thermal sensors

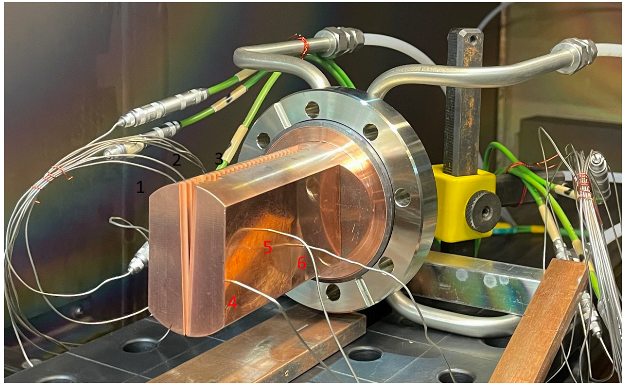
E-beam power transmitted to heat by 75%

- From calibration measurment and
- Verified by outlet water temperature

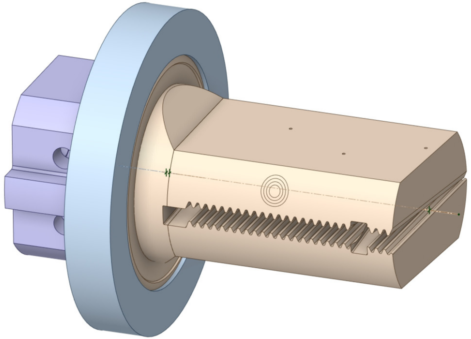
Limitations:

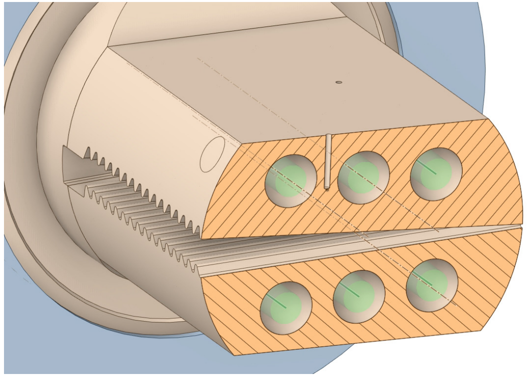
- Power applied on the side wall of absorber jaw. Only one jaw was heated instead of spread of heat on the teeth of both jaws
- Limited chiller water flow rate
- Power density distribution of e-beam is unknown





Prototype Absorber – e-beam power density





By reducing the beam size from 10 mm to 6 mm, the maximum temperature on the absorber body increased significantly from 710 °C to 1080 °C

Temperatures at thermal sensors, which were very close to water channel, remained unchanged

Goal of test

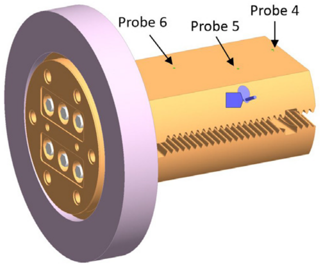
- Investigation of the cooling effect
- Comparison with simulations

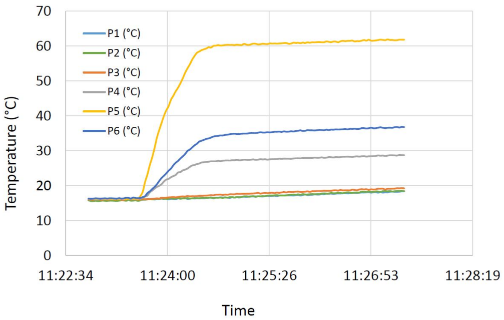
Prototype Absorber – Thermal calculation

Heat power 2790 W

Beam spot size 6 mm

Heat flux 91 W/mm^2





Flow rate 6.7 l/min

Heat transfer coefficient 15.5 kW/(m^{2}K)

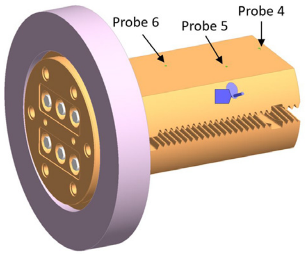
Very high heat transfer is achieved with low flow speed

Temperature at channel wall exceeded the saturation temperature 140 °C at 3.6 bar

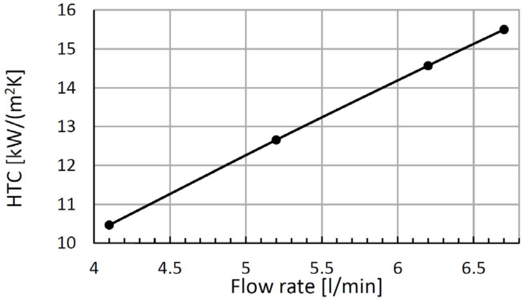
Phase transition initiated

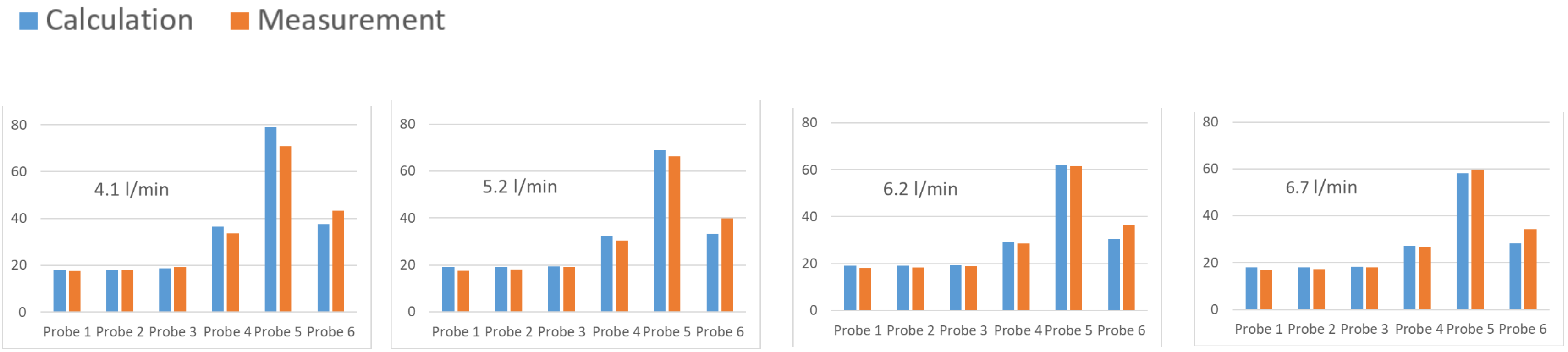
CFD analysis required for temperature profil

Prototype Absorber – Thermal calculation



heat transfer coefficient *h* calculated with relationship to fluid speed *v* by: $h \sim v^{0.8}$





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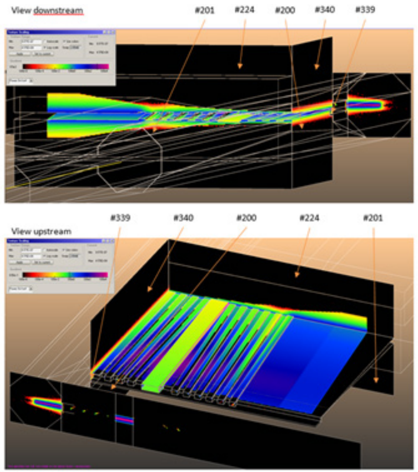
Mechanical design

- The first absorber downstream of 5 T superconducting magnet absorbs 5.9 kW of power
- The rest of the initial 7 kW was sent through a window opening to a second absorber a few meters downstream, which can be transversally aligned
- The small opening angle of only 2 degrees limits the vertical electron beam orbit offset within +/-250 µm
- All components are assembled and brazed together
- Glidcop for all absorbers. The cost of the CuCrZr and Glidcop absorber versions were comparable

Thermal mechanical calculation

Power density from
SYNRAD calculation



ANSYS Thermal calculation
Max. Temperature blow 300 °C

ANSYS mechanical calculation
Max. von Mises stress 200 N/mm^2
The maximum strain was 0.16% and below 0.2% for 10^5 heat loading cycles

Summary

- A thermal mechanical calculation and a CFD simulation using Fluent CHT were compared. Cooling parameters for thermal analysis were verified.
- In a prototype thermal test, phase transition of water was initiated. Considerable heat transfer was achieved and CFD is required. However, it was found that the correlation of the heat transfer coefficient h to fluid speed v by: $h \sim v^{0.8}$ was valid within the range of flow rate in this test.
- The test results validate the absorber's ability to dissipate the specified heat load and the cooling water's capacity to remove the heat. The absorber withstood the 3 kW power on a single jaw without visible damage.
- The final calculation verifies that the absorber’s temperature and stress meet the design requirements.

My thanks go to

- Colette Rosenberg (Vacuum design/Synrad Simulation)
- Romain Ganter (Vacuum /Project management)
- André Weber (Cooling)
- Markus Maehr and Samuel Bugmann (Thermal testing)

- and many others the SLS 2.0 project team
- Demain Lauber from CADFEM