Status task 2.2: Thermal studies

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Outline

- Experimental thermal characterization of the electrical insulations
  - Status on Saclay's work
  - Status on PWR 's work

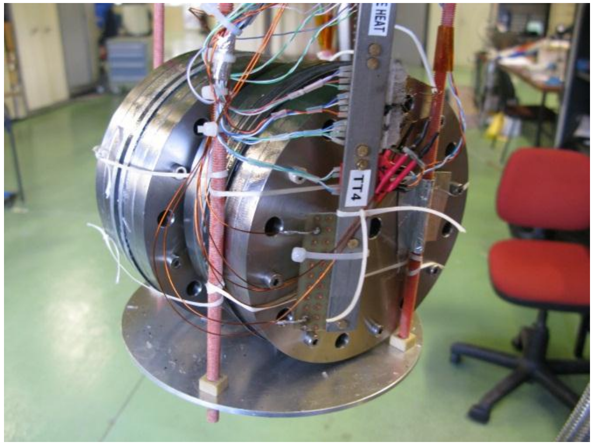
- He II modeling
  - Simplified two-fluid model
  - Implementation in Ansys CFX

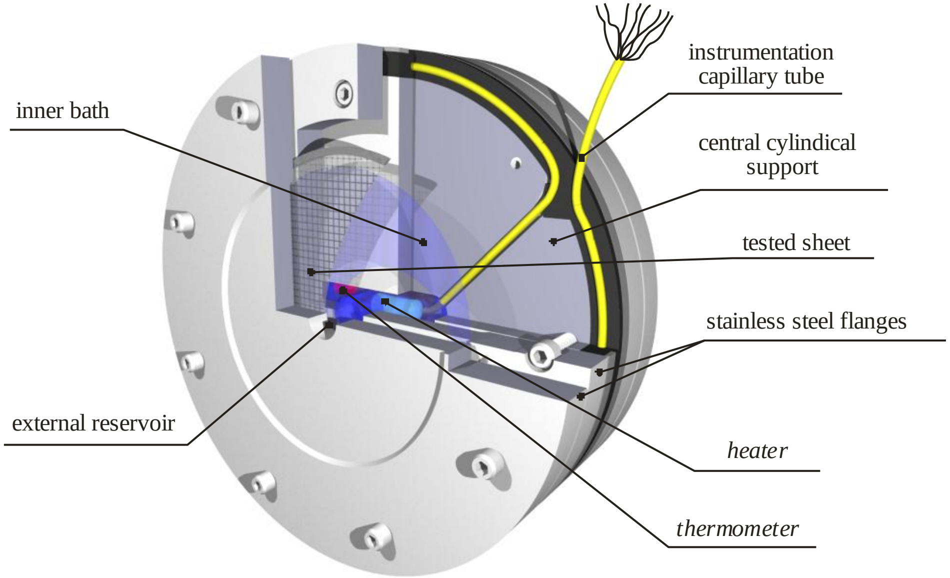
- Fresca 2 thermal model
  - Steady-state results
  - Transient results

Thermal Characterization @ Saclay

☐ He II measurement : thermal conductivity and Kapitza resistance

- ○ Tri-functional epoxy (TGPAP-DETDA) with S-glass fiber
  - 3 samples tests (three thicknesses) from 1.6 K to 2.1 K
- ○ Sample Cyanate ester mix with S-glass fiber
  - 3 samples tests (three thicknesses) from 1.6 K to 2.1 K





TGPAP-DETDA RAL production

Thermal Characterization @ Saclay

- Thermal conductivity
  - Tri-functional epoxy (TGPAP-DETDA)
  - Cyanate ester epoxy mix

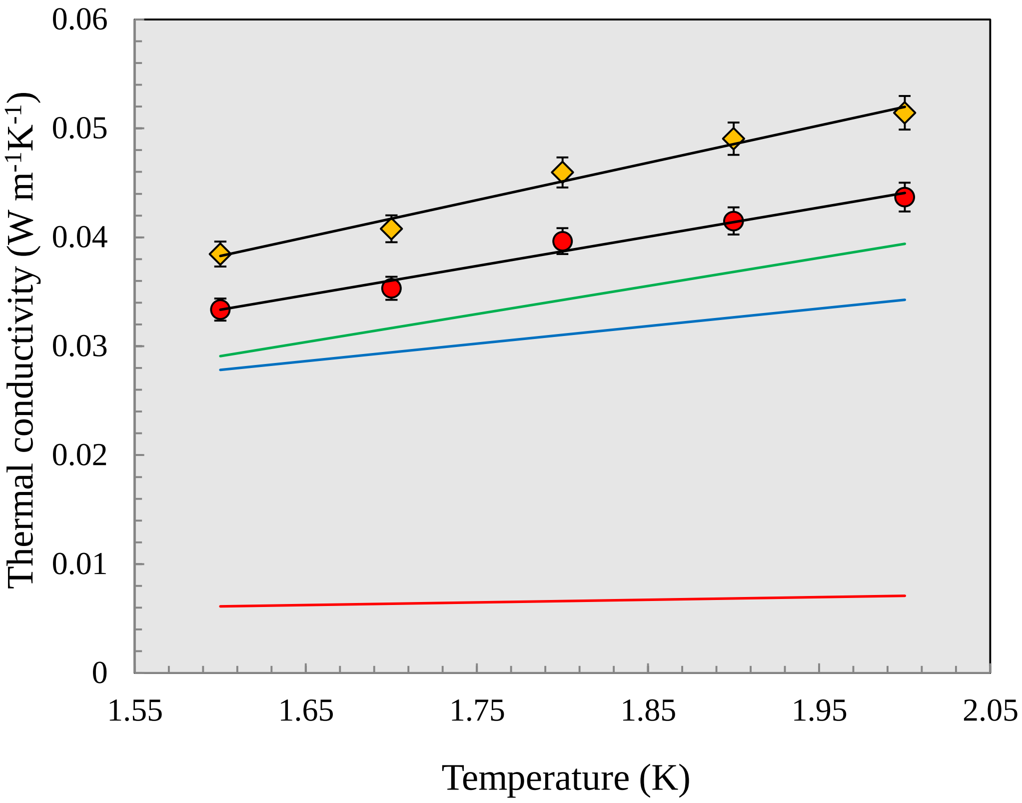
TGPAP-DETDA ◆ [1]

Cyanate ester ● [1]

NED Insulation [2]

Epoxy resin [3]

Kapton [4]



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[1] S. Pietrowicz et al. Thermal conductivity and Kapitza resistance of cyanate ester epoxy mix and tri-functional epoxy electrical insulations at superfluid helium temperature accepted for publication in Cryogenics

[2] Baudouy B., Polinski J., Thermal conductivity and Kapitza resistance of epoxy resin fiberglass tape at superfluid helium temperature, Cryogenics 2009, 49, 138-143

[3] Crycomp, 3.06 version, Florence (SC, USA): Cryodata Inc.

[4] Baudouy B., Kapitza resistance and thermal conductivity of Kapton in superfluid helium, Cryogenics 2003; 43 (12): 667-672.

Thermal characterization @ Saclay

- ☐ Kapitza resistance
  - ○ Tri-functional epoxy (TGPAP-DETDA)
  - ○ Cyanate ester epoxy mix

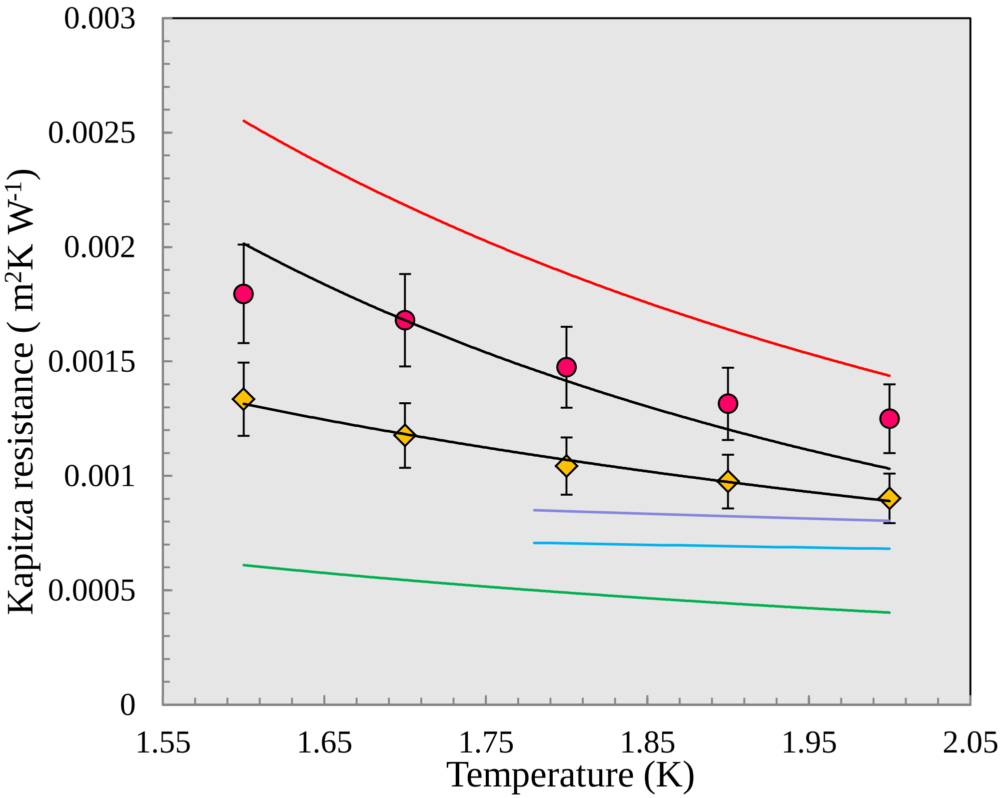
TGPAP-DETDA	◆	[1]
Cyanate ester	●	[1]

NED Insulation [2]

Kapton [4]

Stycast coating on polished surface [5]

Stycast coating on oxidized surface [5]



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[5] Iwamoto A., Maekawa R., Mito T., Kapitza conductance of an oxidized copper surface in saturated He II. Cryogenics 2001, 41, 367-371

PWR He II cryostat status (© J. Polinski)

Top view of the cryostat with wiring

- Instrumentation is installed
- Connection of instrumentation to DAQ system is done
- LabView program for cryostat operation is done
- 4 thickness of unirradiated 71 Mix samples are ready for thermal test
- During the first cool down with LHe some technical problems occurred
  - The manual shut-off valve need to be exchanged
  - Restart of measurement expected in mid of Dec 2011

He II modeling

- The momentum equations for the superfluid component is simplified to the form [6]

$$s\nabla T = -A\rho_n|u_n - u_s|^2(u_n - u_s)$$

(the thermomechanical effect term and the Gorter-Mellink mutual friction term are larger than the other)

Superfluid component:

$$u_s = u - \frac{\rho_n}{\rho}(u_n - u_s) = u + \left(\frac{\rho_n^3 s}{A\,\rho^3\rho_n|\nabla T|^2}\right)^{1/3}\nabla T$$

Normal component:

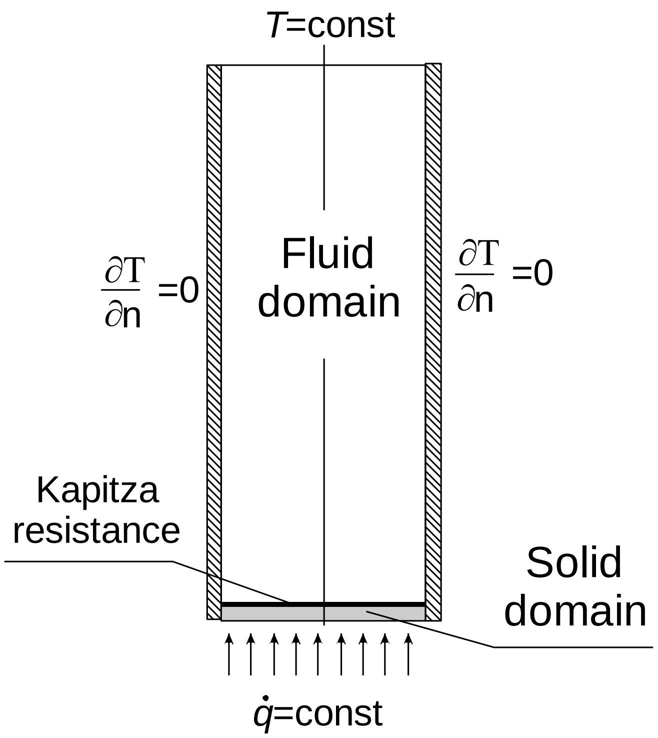
$$u_n = u + \frac{\rho_s}{\rho}(u_n - u_s) = u - \left(\frac{\rho_s^3 s}{A\,\rho^3\rho_n|\nabla T|^2}\right)^{1/3}\nabla T$$

Momentum equation

$$\rho\frac{\partial u}{\partial \tau} = -\rho(u\cdot\nabla)u - \nabla p - \nabla\cdot\left[\frac{\rho_n\,\rho_s}{\rho}\left(\frac{s}{A\rho_n|\nabla T|^2}\right)^{2/3}\nabla T\nabla T\right]$$
$$+\,\eta\left[\nabla^2 u + \frac{1}{3}\nabla(\nabla\cdot u) - \left(\frac{\rho_s^3 s}{A\rho^3\rho_n|\nabla T|^2}\right)^{1/3}\left\{\nabla^2(\nabla T) + \frac{1}{3}\nabla(\nabla\cdot\nabla)T\right\}\right] + \rho g$$

[6] Kitamura, T. Numerical model on transient, two-dimensional flow and heat transfer in He II, Cryogenics,vol. 31, 1, 1997, p. 1-9

He II modeling



1. For He II (fluid domain)

☐ $\displaystyle \frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\, u) = 0$

☐ $\displaystyle \rho\frac{\partial u}{\partial\tau} = -\rho(u\cdot\nabla)u - \nabla p - \nabla\cdot\left[\frac{\rho_n\,\rho_s}{\rho}\left(\frac{s}{A\rho_n|\nabla T|^2}\right)^{2/3}\nabla T\nabla T\right]$
$\displaystyle +\eta\left[\nabla^2 u + \frac{1}{3}\nabla(\nabla\cdot u) - \left(\frac{\rho_s^3 s}{A\rho^3\rho_n|\nabla T|^2}\right)^{1/3}\left\{\nabla^2(\nabla T) + \frac{1}{3}\nabla(\nabla\cdot\nabla)T\right\}\right] + \rho g$

☐ $\displaystyle \rho c_p\frac{\partial T}{\partial\tau} = -\rho c_p(u\cdot\nabla)T - \nabla\cdot\left\{\left(\frac{1}{f(T)|\nabla T|^2}\right)^{1/3}\nabla T\right\}$

2. Insulation (solid domain)

☐ $\displaystyle \rho_{solid}\, c_p(T)\frac{\partial T}{\partial\tau} = \left[\frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k(T)\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)\right]$

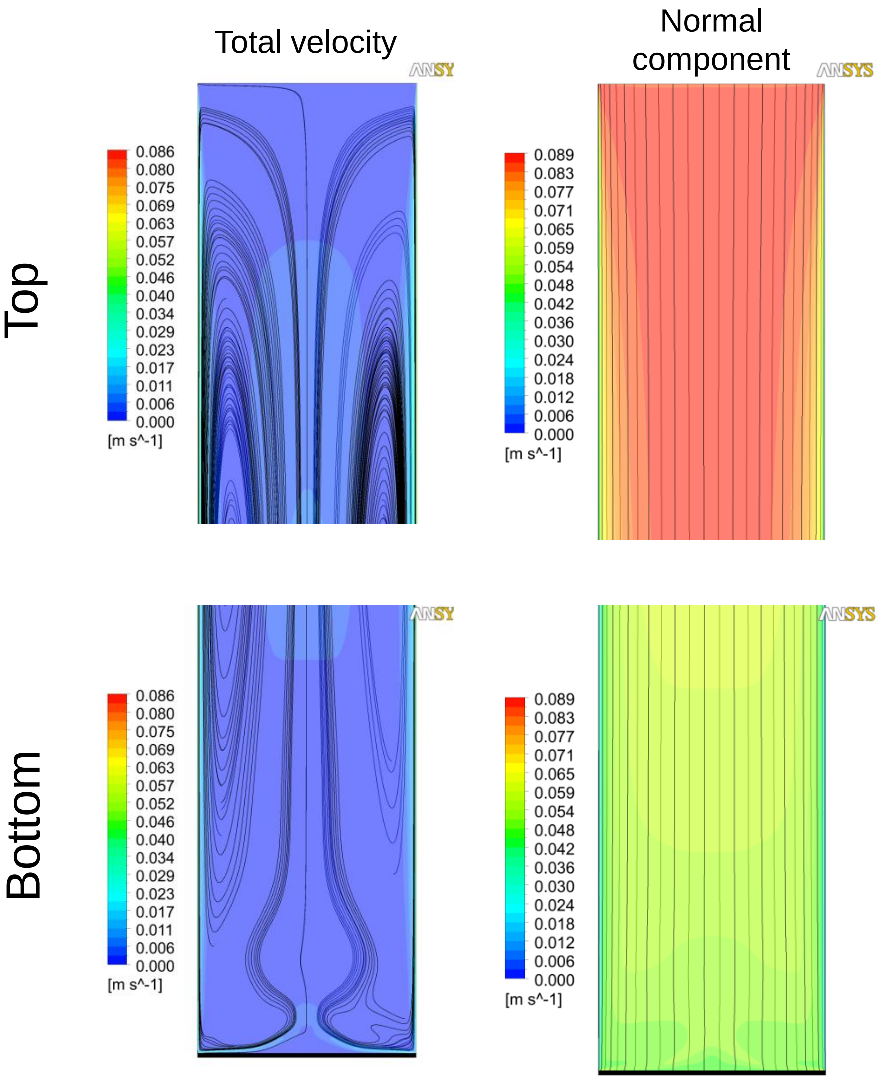
3. Kapitza resistance R_k as a function of temperature

Boundary conditions

on left and right – adiabatic condition	$\frac{\partial T}{\partial n} = 0$
on the top – constant temperature	T_b=1.95 K
on the bottom – constant heat flux	q=const

on all walls $u_\perp = 0$ and $u_\parallel = \left(\frac{\rho_s^3 s}{A\,\rho^3\rho_n|\nabla T|^2}\right)^{1/3}(\nabla T)_\parallel$

He II modeling

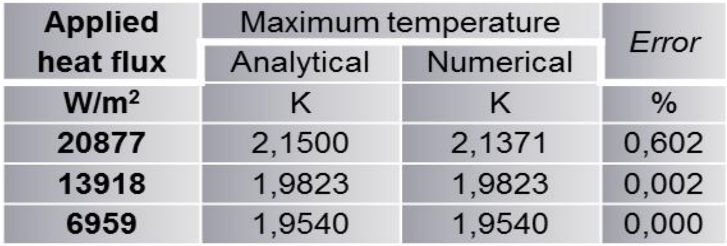

Total velocity

Normal component

Top

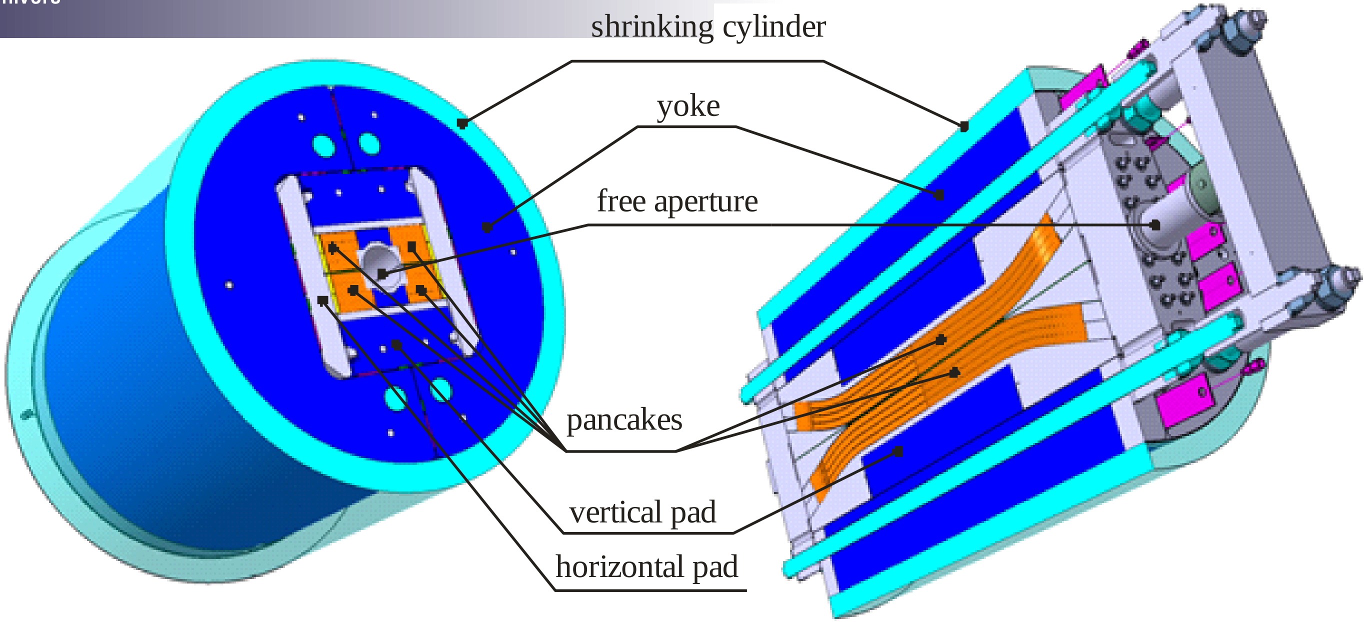
Bottom

20877 W/m²



Applied heat flux	Maximum temperature		*Error*
	Analytical	Numerical	
W/m²	K	K	%
20877	2,1500	2,1371	0,602
13918	1,9823	1,9823	0,002
6959	1,9540	1,9540	0,000

Fresca 2 thermal modeling



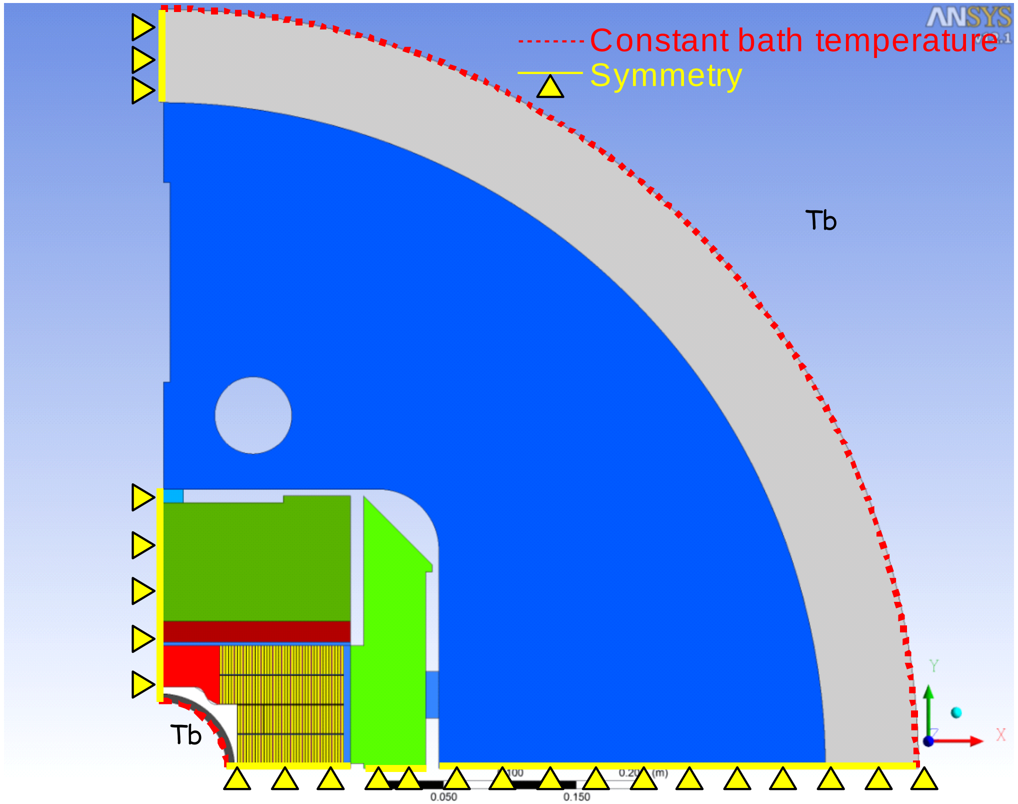
MAGNET SPECIFICATION

- type: block coil, 156 conductors in one pole;
- free aperture: 100 mm;
- total length: 1600 mm;
- outside diameter: 1030 mm;
- magnetic field: 13 T;

OPERATING PARAMETERS

- coolant: superfluid and/or saturated helium;
- temperature: 1.9 K and/or 4.2 K;
- temperature operating margin: 5.8 K at 1.9 K and 3.5 K at 4.2 K

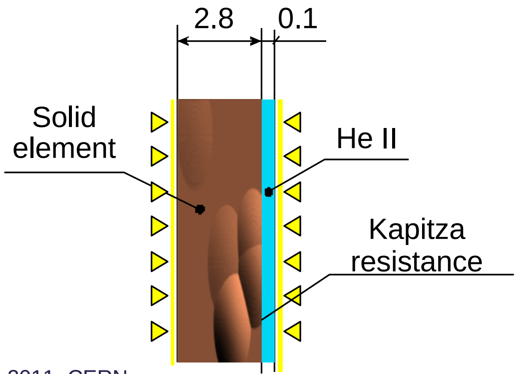
Fresca 2 thermal modeling

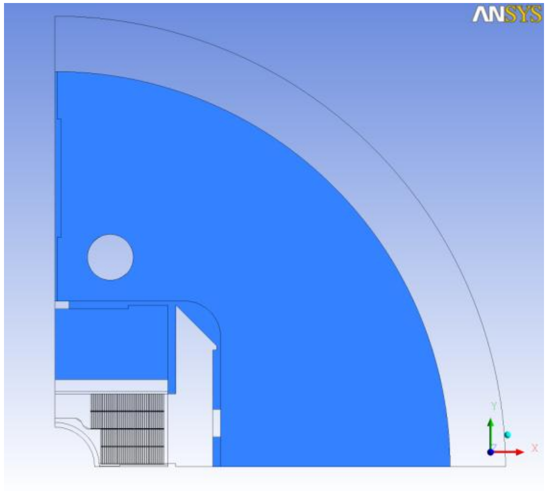


Assumptions

- Two types of boundary conditions:
  1. Kapitza resistance on walls (red lines);
  2. Symmetry (yellow lines);
- Thermal conductivity as function of temperature;
- Perfect contact between solid elements;
- Calculations are carried out for CUDI model (AC loss due to ISCC losses, non-homogenous spreads)
- He II between yoke and pad laminations (200 μm)

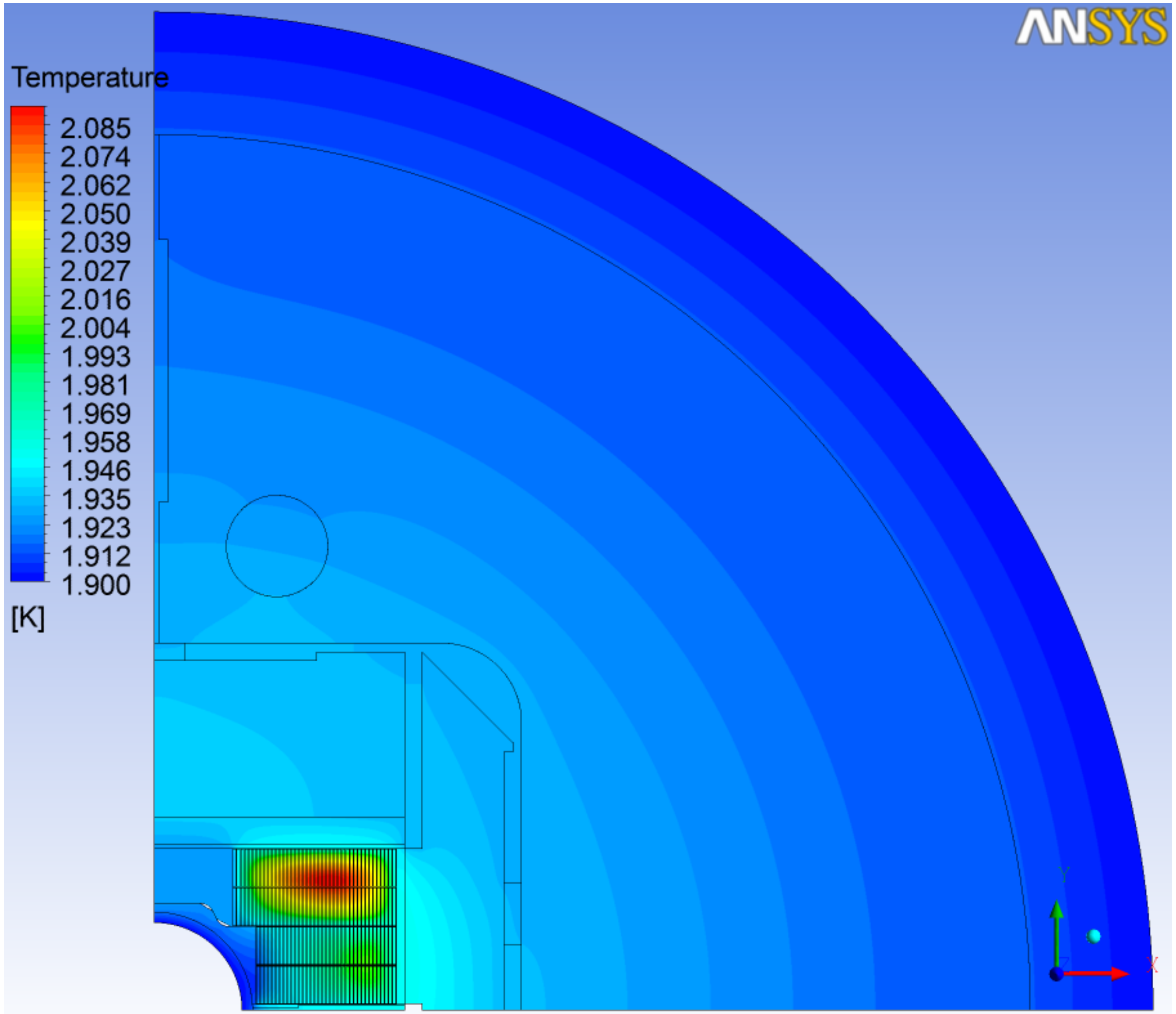
Geometry and boundary conditions applied during simulations

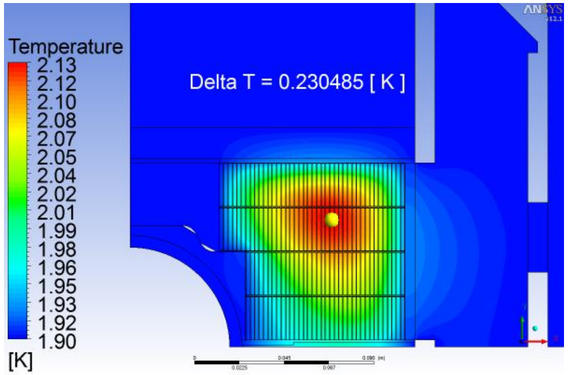




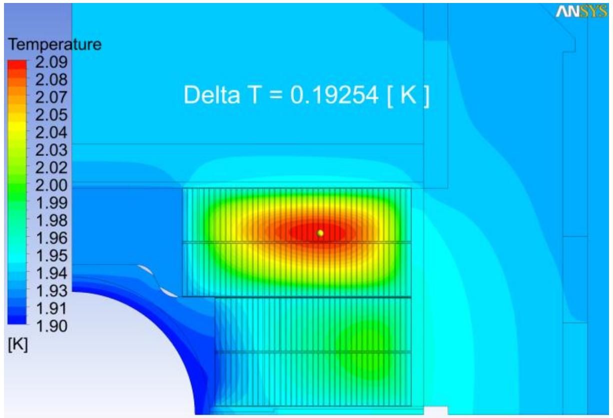
Fresca 2 thermal modeling – Steady State

The distribution map of temperature in the magnet (the plane is located on symmetry of helium side)





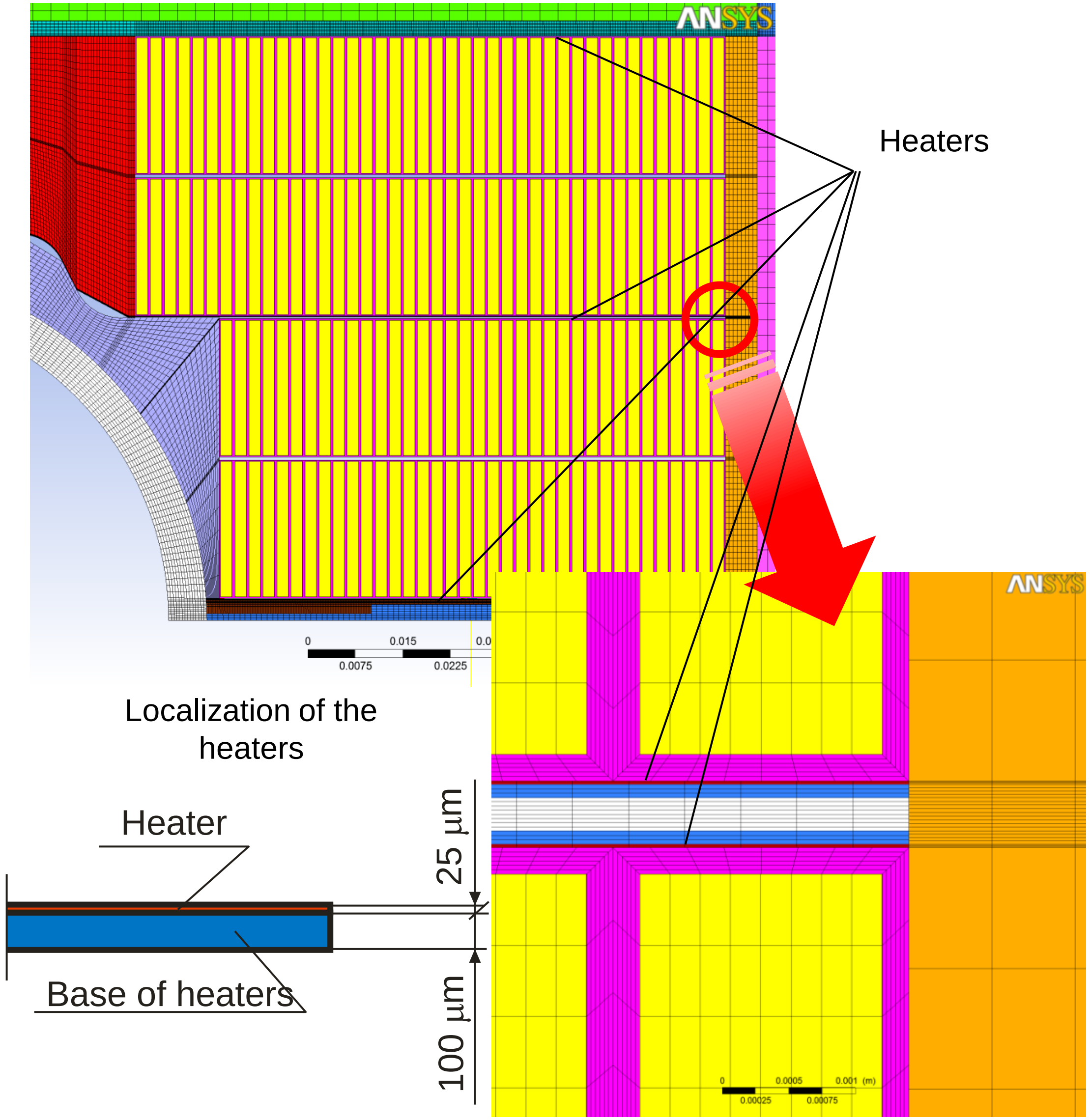
S. Pietrowicz, B. Baudouy, Thermal design of an Nb_3Sn high field accelerator magnet, CEC 2011, Spokane, USA, accepted for publication



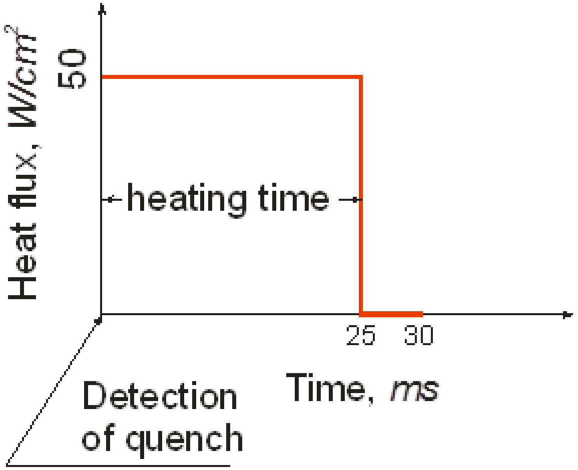
S. Pietrowicz, B. Baudouy, *Numerical study of the thermal behavior of a Nb_3Sn high field magnet in He II presented at CHATS October 2011 CERN*

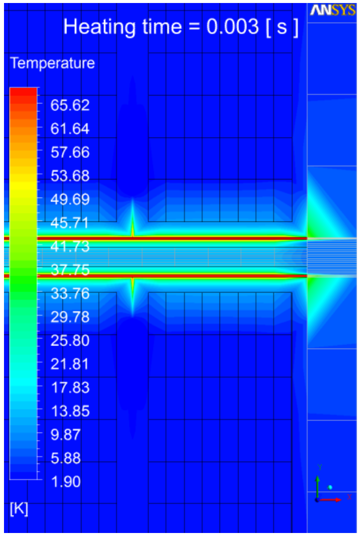
[7] de Rapper, W. M., "Estimation of AC loss due to ISCC losses in the HFM conductor and coil", CERN TE-Note-2010-004, 2010;

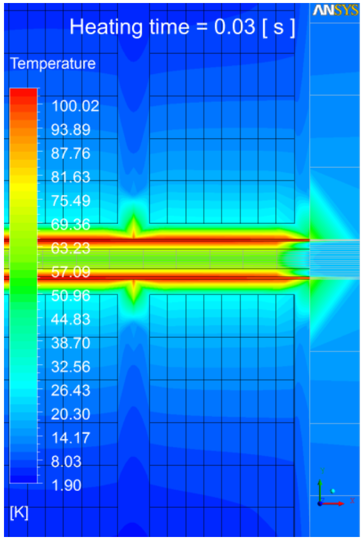
Fresca 2 thermal modeling – Transient



Localization of the heaters







Status and Future

- Thermal test of electrical insulations
  - Tri-functional (TGPAP-DETDA) and cyanate ester with S-glass fiber done and analyzed
  - *Tests to be started in mid Dec. 2011 for the RAL Mix 71 and RAL Mix 237 (PWR)*
  - *Test for the irradiated samples in 2012*

- A He II simplified model is running under ANSYS CFX Software
  - Steady-state and transient calculation implementations
  - Model benchmarked against analytical solution within few percents
  - *Improvement of the model during 2012*

- Thermal modeling of Fresca 2
  - $\Delta T=193$ mK for the AC losses given by the CUDI model [7]
  - The transient code is operational
  - *Calculations on newer versions in 2012*