

Thermal Design and Performance results of the first High-Beta Cryo-module for HIE-ISOLDE at CERN

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Introduction

The High Energy and Intensity HIE-ISOLDE is a facility under construction at CERN whose target is ultimately to produce radioactive ion beams at 10MeV/u maximum energy in order to significantly expand the nuclear physics programme carried out by REX-ISOLDE. A Finite Elements model has been developed in order to generate a faithful global mapping of temperatures and heat fluxes inside the cryo-module. Combined with the experimental results of the first test campaign, it will serve as an optimization tool for the future cryo-modules in terms of improvement in the global and specific heat loads management.

Objectives

- ❖ Global temperature and heat flux mapping of the entire cryo-module in order to assess its thermal performance;
- ❖ Validation and diagnostic tool for interpreting the experimental data obtained from numerous temperature sensors located inside the cryo-module;
- ❖ Advanced thermal analysis on specific cases in order to benchmark and optimize their design under nominal operational conditions.

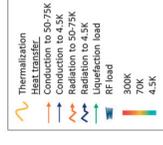
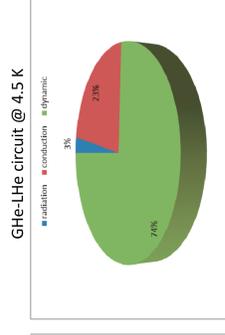
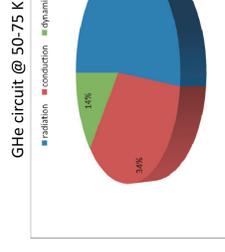
Main design requirements:

- ❖ Accurate alignment and precise location within few tenths of mm with respect to the beam axis for the RF cavities and the solenoid magnet;
- ❖ Cleanliness of the surfaces of the RF cavities in order to preserve their performance, extremely sensitive to particulate contamination;
- ❖ Temperature distribution on the cavities < 1K;
- ❖ Thermally insulate from heat in-leaks within budgets;
- ❖ Ultra High Vacuum (<10⁻⁸ mbar at cold) and leak tightness to better than 1x10⁻¹¹ Pa m³ s⁻¹;
- ❖ ISO5 (Class100) assembly compatibility.



Global heat transfer

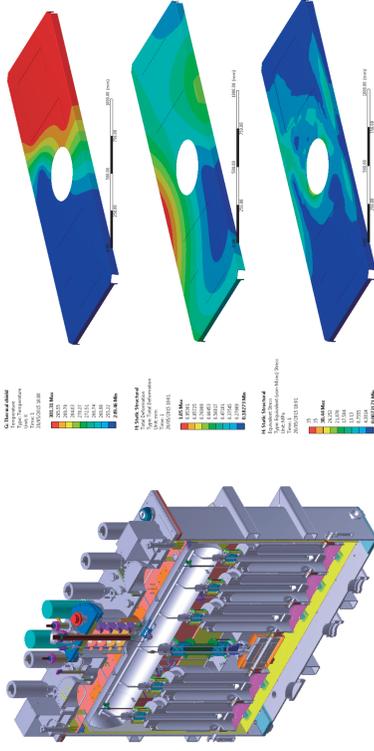
In steady-state mode, two independent cryogenic circuits, a 50-75 K gaseous helium line and a 4.5 K bi-phase GHe-LHe line, provide a continuous active thermal control. The five RF superconducting cavities, dissipating a nominal heat of 10W each, and the solenoid are connected to the helium reservoir and filled with liquid helium maintained at 4.5 K constant temperature and 1.3 bars pressure.



Conclusions and Next Steps

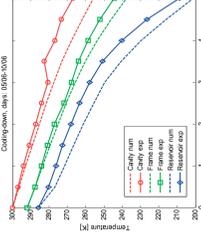
- ❖ On May 2015 the first high-beta HIE-ISOLDE Cryo-module has been delivered to the beam line, connected to the cryogenic distribution and tested during summer 2015. The first cool-down of the cryo-module has been carried out in June 2015;
- ❖ The global performance of the entire cryo-module and of its components has been modelled and analyzed through a Finite Elements model built on ANSYS in agreement with the European Cooperation for Space Standardization recommendations;
- ❖ A preliminary correlation between the analysis and the tests results of the cool-down has been performed. A good agreement between the experimental and numerical set of data has been obtained;
- ❖ Some specific cases, i.e. omega plates and current leads, have been studied and tested in order to validate their design and to find their best operative working conditions;
- ❖ The complete validation of the FE model will be carried out as soon as all the experimental data coming from the different thermal modes is available (evaluation of the emissivity of the thermal shield, etc.).

Thermal model:

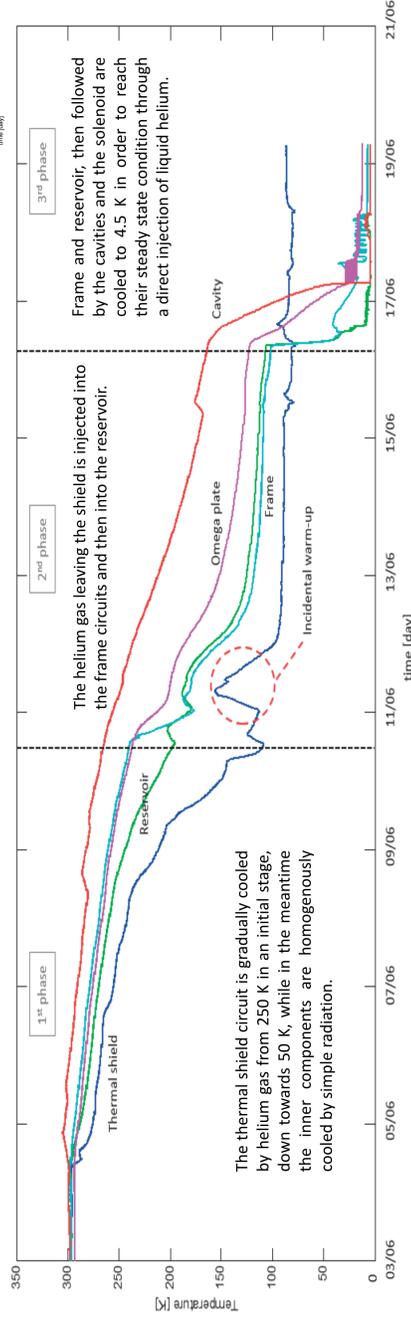


During this phase the maximum thermal excursion across the thermal shield top plate is controlled to keep below 50 K, in order to ensure a maximum von-Mises stress of 30 MPa.

Good agreement between the experimental data and the numerical simulations performed with the FE model.



First cool-down:



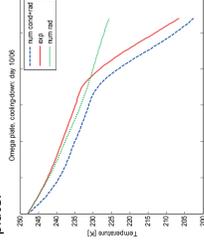
The thermal shield circuit is gradually cooled by helium gas from 250 K in an initial stage, down towards 50 K, while in the meantime the inner components are homogeneously cooled by simple radiation.

The helium gas leaving the shield is injected into the frame circuits and then into the reservoir.

Frame and reservoir, then followed by the cavities and the solenoid are cooled to 4.5 K in order to reach their steady state condition through a direct injection of liquid helium.

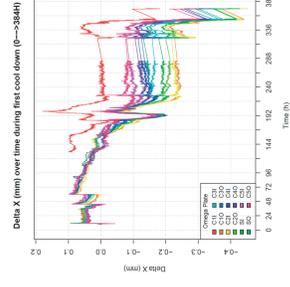
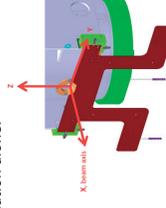
Omega plate

In order to facilitate the temperature distribution by simple conduction along the structure, two thermalisations are mechanically connected between the support frame and each omega plate.



The two thermalisations have improved the temperature management forcing the behaviour of the frame rather than being cooled by radiation alone.

During the cool-down the Mathilde system has continuously measured the displacements of the reference points on the targets attached to the omega plates.



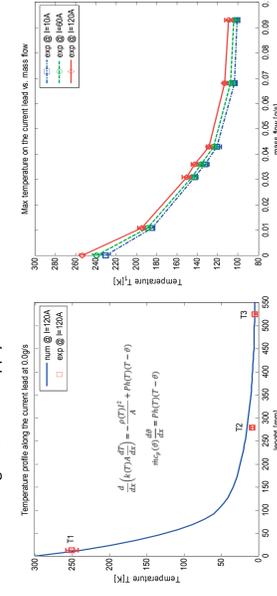
Current leads and solenoid splices

The cryogenic heat load due to solid conduction and ohmic heating in the resistive leads has to be optimised in order to minimise helium boil-off and the liquefaction inventory.



The electrical splice connection to the solenoid wires is made by a mechanical clamping with a bolted connection assembled with a given torque to minimize the electrical resistance.

Numerical calculations are confirmed by a high measured temperature gradient just in the top quarter of the lead with an almost uniform temperature equal to the temperature of the liquid bath over the remaining length. The temperature at the top of the current lead is dependent on the mass flow rate and on the ohmic heating due to the supply current.



Credits: Guillaume Kautzmann, EN-MEF-SU, CERN.