AN APPROACH FOR COMPONENT-LEVEL ANALYSIS OF CRYOGENIC PROCESS IN SUPERCONDUCTING LINAC CRYOMODULES

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Abstract

Powerful superconducting linear accelerators feature accelerating sections consisting in a series of cryomodules (CM), each hosting superconducting radiofrequency (SRF) cavities cooled by a cryogenic process. Despite the extensive instrumentation used for the tests and validation of the prototype cryomodules, it is usually very complex to link the measured global thermodynamic efficiency to the individual component performance. Previous works showed methods for assessing the global efficiency and even for allocating performances to sets of components, but few went down to a component level. For that purpose, we developed a set of techniques based on customized instrumentation, on dedicated test protocols, and on model-based analysis tools. In practice, we exposed the components to various operating conditions and we compared the measured data to the results from a detailed dynamic component model at the same conditions. This method was applied to the cryogenic debugging phase of the tests of the MINERVA prototype cryomodule, which, despite the liquid helium shortage, led to an extensively detailed characterization, for its validation towards the serial construction.

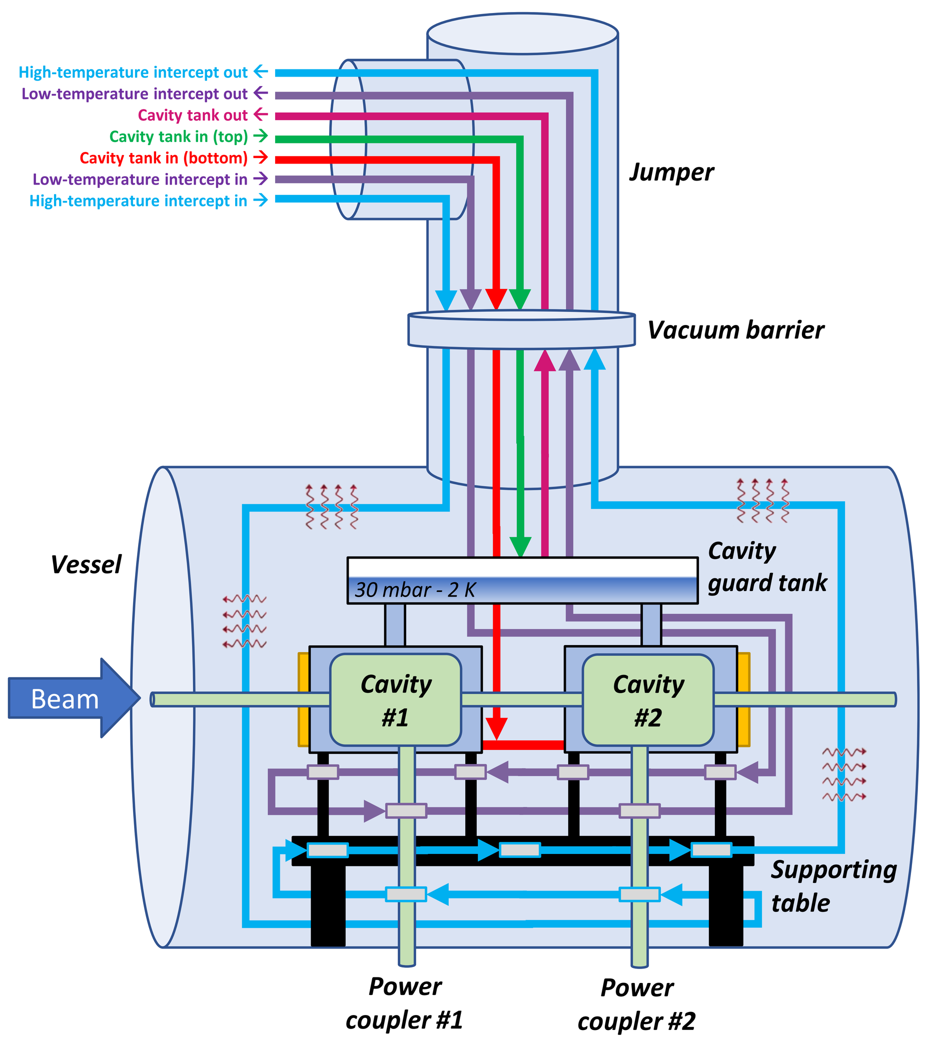
The MINERVA prototype cryomodule

Cryogenic process (in prototype test mode)

- A main helium loop at 2 K by saturated helium at 30 mbar
- A high-temperature intercept at about 80 K
- A low-temperature intercept between 5 and 10 K

Problematic

- Many heat sources & complex thermal paths
- Rare opportunities to measure them
- Long cryogenic transients but limited test time
- Need for a heat load project reference
- Often 1 global heat load measurement

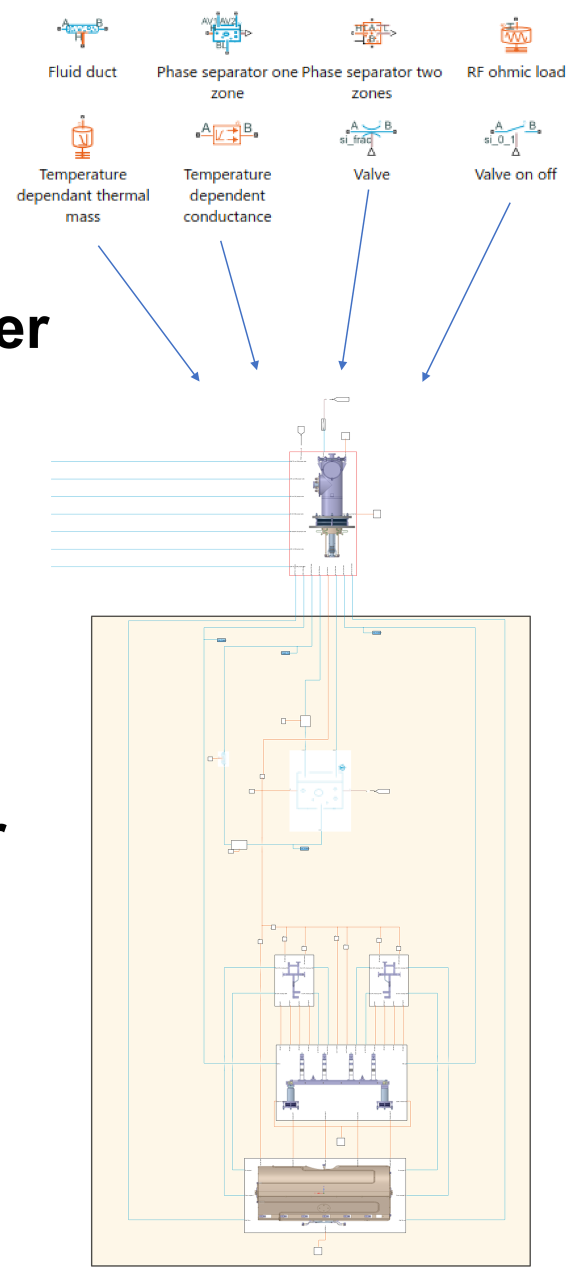


→ **Need for a tool to break-down the heat loads**

Tool creation and methodology

The cryogenic simulation tool

- Customized library of Simscape blocks based on MATLAB / Simulink
- Solving for transient **fluid** and **heat transfer**
- **Multi-physics**



The heat load analysis method

- Create a **detailed model** based on thorough investigations of what was built
- Calculate the **error** over the whole **sensor output** and **test condition** range
- Trim the "free" parameters to minimize the error

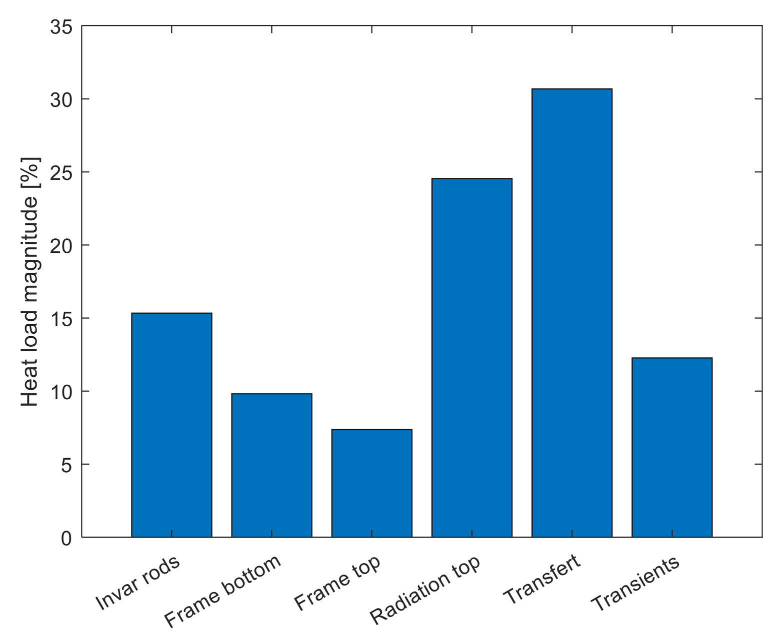
→ **Search for global consistency rather that 100% accuracy on one output**

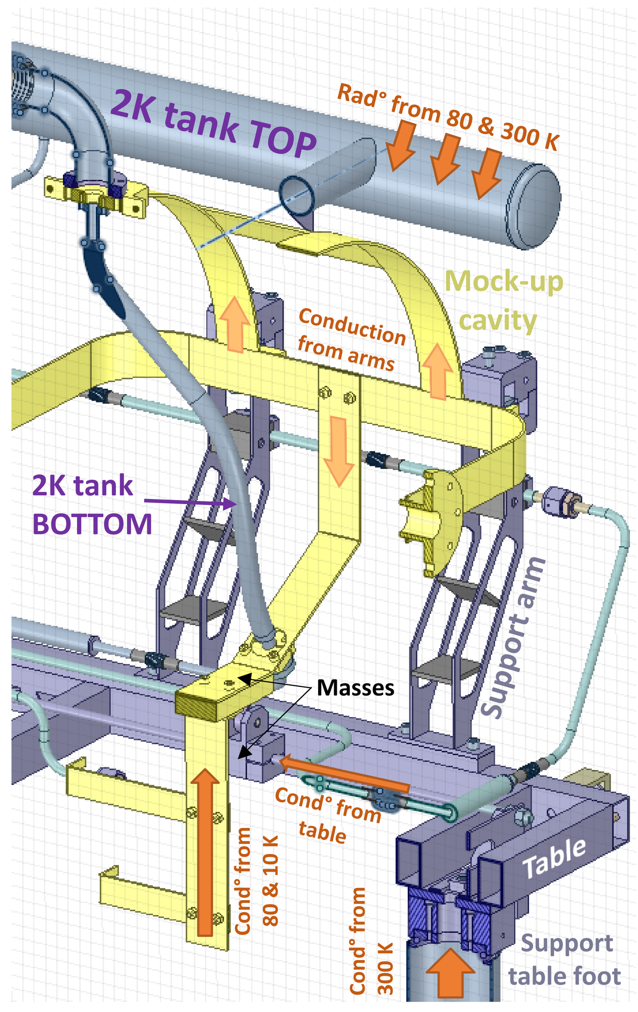
Example #1: heat balance to the 2K tank

Case study: heat load distribution on a 2 K tank, with many heat sources, in transient state

- Reproduction of many tests conditions, as temperature, level, cryogenic fluids

→ **Enabled to spot unexpectedly high contributions, to further investigate**



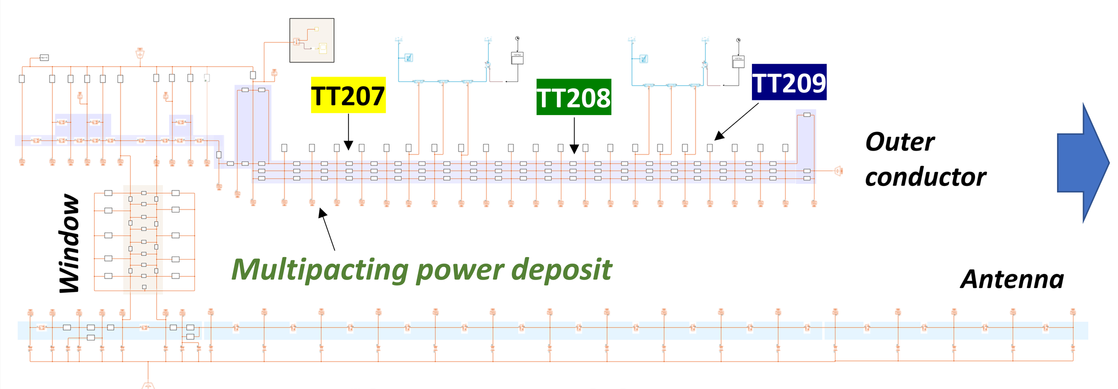


Example #2: coupler multipacting heat load

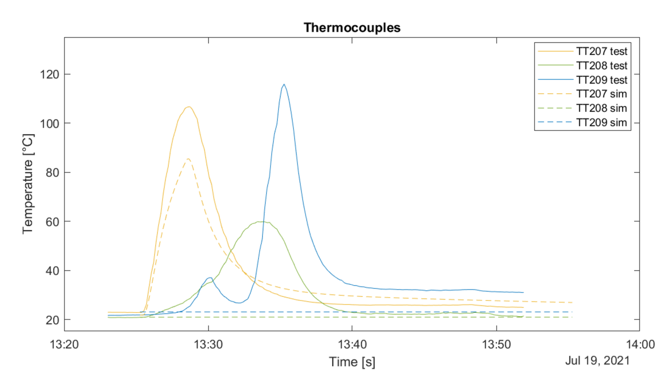
Case study: unexpectedly high heat loads deposited on the coupler external conductor, during warm conditioning

Questions: what heat load magnitude? Which location? Static?

- 1D transient simulations
- Correlation with multiple sensors and multipacting simulations



Simscape model



Tests VS simulation

About the author: after 8 years as an engineer in the combustion engine industry, Cédric Lhomme is presently in the 2nd year of its PhD studies (defense in October 2023) at the PHENIICS doctoral School in the Paris-Saclay perimeter.

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