中山先进低温技术研究院
Zhongshan Institute of Advanced Cryogenic Technology
Email: uwu@mail.ustc.edu.cn, wangqian@ziac.cn

Session: Wed-Po-2.1 ID: #503
ICEC/ICMC
29th International Cryogenic Engineering Conference
International Cryogenic Materials Conference 2024
July 22-26, 2024, Geneva, Switzerland

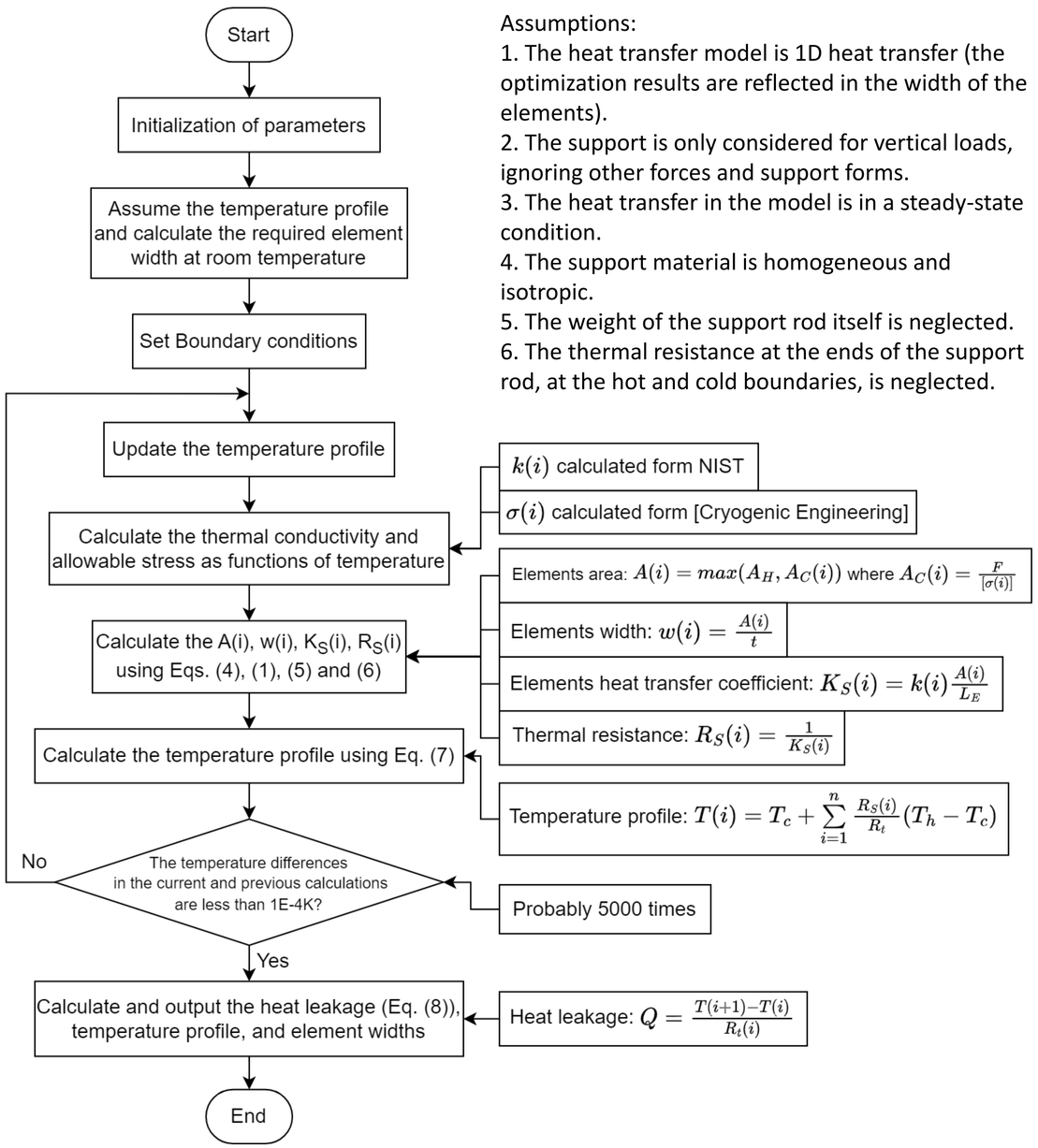
Topology optimization of cryogenic heat transfer in 1D stressed rods for large liquid hydrogen tanks

Shixian Wu [a,], Xinyuan Liu [a], Jiancheng Tang [a,b], Linghui Gong [a,b], Liqiang Liu [a,b], Qian Wang [a,*]*
[a] Zhongshan Institute of Advanced Cryogenic Technology, Zhongshan 528400, P. R. China
[b] Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100080, P. R. China

Abstract

The heat leakage of cryogenic equipment mainly comes from multilayer insulation and solid heat conduction. However, optimizing solid heat transfer has not been extensively studied. Utilizing the properties of materials that exhibit increased strength and reduced thermal conductivity at cryogenic temperatures, the shape of a 1D support was optimized through topology optimization. The shape, temperature profile, and heat transfer coefficient of the support were analyzed, as well as the impact of different weight ratios of liquid hydrogen on heat leakage.

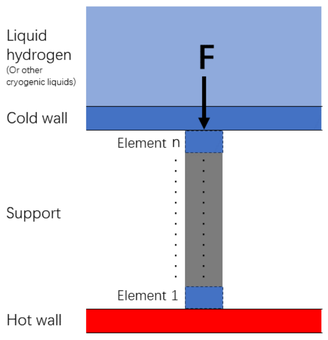
Flowchart



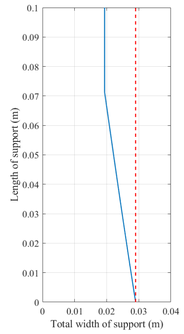
Assumptions:
1. The heat transfer model is 1D heat transfer (the optimization results are reflected in the width of the elements).
2. The support is only considered for vertical loads, ignoring other forces and support forms.
3. The heat transfer in the model is in a steady-state condition.
4. The support material is homogeneous and isotropic.
5. The weight of the support rod itself is neglected.
6. The thermal resistance at the ends of the support rod, at the hot and cold boundaries, is neglected.

Analysis

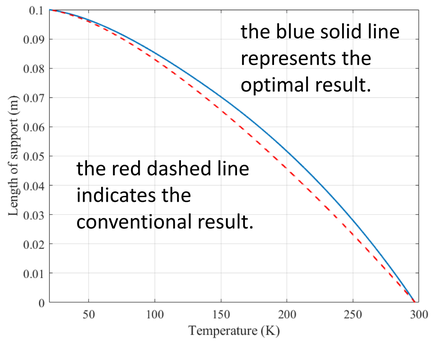
load conditions



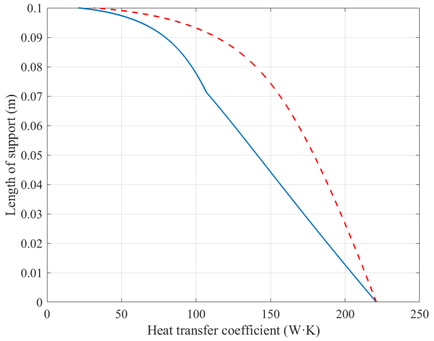
Width distribution



Temperature profile



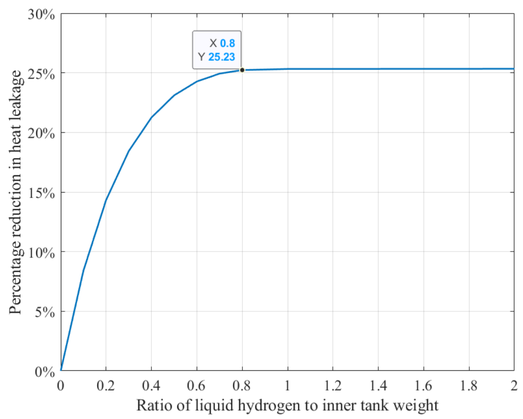
Heat transfer coefficient distribution



304 stainless steel is used as an example here. The ratio of the liquid hydrogen weight to the inner container weight is set to 0.5.

- A simple one-dimensional vertical compression support rod model was used.
- The top of the rod is subjected to the gravitational force from both the inner container and the liquid hydrogen.
- As the temperature decreases, the allowable stress gradually increases, and the support width gradually decreases until it no longer changes near 0.07m.
- This is because the support width has reached the minimum required width at room temperature (without liquid hydrogen).
- This near-linear width distribution is due to the material properties used.
- The thermal resistance on the cryogenic side has increased relative to the high-temperature side.
- The thermal conductivity has decreased across the entire support.
- The maximal disparity in thermal conductivity occurs in the middle region.
- At the cryogenic end, the difference is about 10 W/K.

Results



- This optimization method is highly effective in reducing heat leakage in cryogenic supports.
- The effectiveness of the support optimization is significantly influenced by the weight ratio of the liquid hydrogen.
- When the weight ratio of the liquid hydrogen to the inner container of the tank is 0.2, 0.4, and 0.6, the percentage reduction in heat leakage rapidly increases, reaching 14.33%, 21.25%, and 24.27%, respectively.
- Finally, when the weight ratio reaches 0.8, the reduction in heat leakage percentage stabilizes, achieving a maximum reduction of 25.23%.