Cryogenic Heat Sink for Helium Gas Cooled Superconducting Power Devices

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Abstract

Power cables have terminations on either end to guarantee dielectric integrity: They interconnect the power cable with its high electric field to air-insulated parts with their lower electric fields in changing ambient conditions. In case of a superconducting power cable, the terminations additionally need to link the cryogenic environment in the cable with the room temperature environment of the non-superconducting elements of the power system, such as copper cables, power transformers, circuit breakers, instrumentation transformers, or disconnect switches. The higher temperatures of these components cause substantial heat influx into the termination and consequently into the superconducting cable. It is of utmost importance to minimize the heat influx to maintain the operating temperature of the superconducting cable as well as to minimize the installed cryogenic capacity and operating costs of the superconducting cable system. The standard method of cooling for high temperature superconducting power devices is to use liquid nitrogen in the temperature range of 68–77 K. However, the cable type investigated in this study uses cryogenic helium gas at elevated pressure as coolant. The choice of coolant is driven by the intended application for shipboard power systems, where the use of liquid cryogens poses potential unacceptable asphyxiation hazards as well as high pressure hazards associated with phase change [1]. However, gaseous helium makes the cable more sensitive to heat influx since the heat capacity of helium gas is inferior to that of liquid nitrogen. A heat sink is required to intercept the heat leak from the room temperature components to the superconducting cable. The heat sink designed and modeled in this study is made of copper and features 18 fins of 10 cm length. It is integrated in a cylindrical copper tube, flattened on the bottom side. The flat surface allows to attach the thermal load. Cryogenic helium gas is injected at high pressure by an external helium circulation system [2]. The input temperature and pressure at the heat sink are fixed at 50 K and 1.82 MPa, respectively. Heat sink and connections are enclosed in a vacuum chamber to reduce the heat transfer from the ambient. This particular heat sink is for model validation only. It is roughly half of the size of the heat sink for the superconducting cable. A model has been developed using the Conjugate Heat Transfer physics in COMSOL Multiphysics 4.3 to simulate the stationary, three dimensional fluid flow and heat transfer. The fluid velocity field was low enough to assume laminar flow and it was not necessary to implement a turbulence model. The model was used to find a geometry that allows high heat transfer from the copper surface to the gaseous helium stream. At the same time, the pressure drop in the helium system had to be kept minimal to maintain the required helium gas flow rate to the cable. Experiments are being designed to validate the model.

Reference

1. J.T. Kephart et al., “High Temperature Superconducting Degaussing from Feasibility Study to Fleet Adoption,” IEEE Trans. on Applied Superconductivity, Vol. 21, p. 2229-2232 (2011).
2. S. Pamidi et al., “Cryogenic helium gas circulation system for advanced characterization of superconducting cables and other devices,” Cryogenics, Vol. 52, p. 315-320 (2012).

Figures used in the abstract

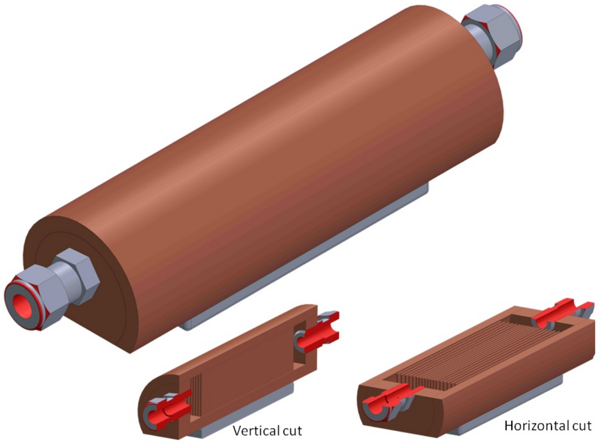

Figure 1: Design of the heat sink (total view) and cut views to show the internal fin structure (vertical and horizontal cut).

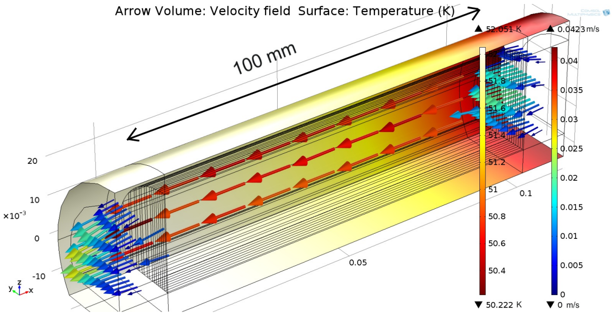

Figure 2: Surface temperature of the heat sink along with the velocity field of the coolant flow.