Modular nitrogen boiling thermosyphons for multi-kiloampere current lead cooling

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Motivation

High current lead heat loads form a common challenge in superconducting experiments (~50 W/kA/optimal lead (thermal-conduction-only) [1]

- ❖ Requires large reliable cryogenic systems (large experiments); or
- ❖ High-power cryocoolers (conduction-cooled systems).

➢ Install **separate heat interceptor** module based on **nitrogen boiling heat uptake.**

- Connected to separate flow circuit, room-temp top connector and HTS bottom connector (Fig. 1).
- Thermosyphon effect offers **passive, safe & reliable flow circuit**.
- LN_2 is relatively **cheap, widely available and easy to use**.
- Focus on a **conceptually and practically simple design**.

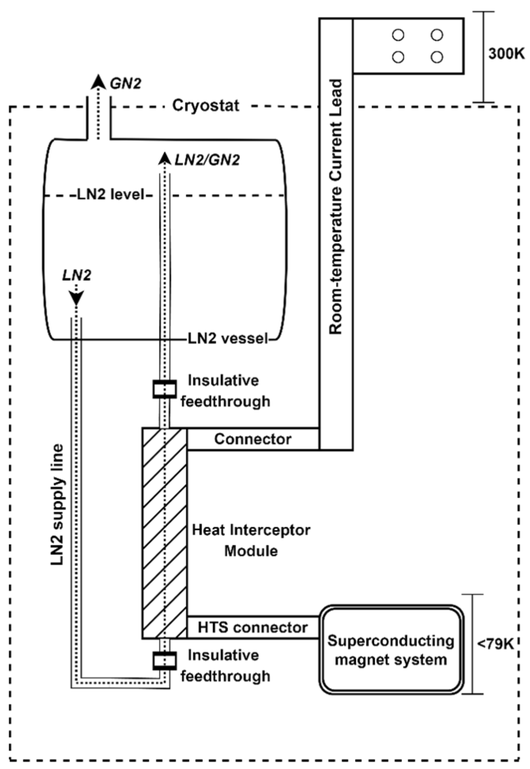


***Fig. 1** - System illustration with modular heat interceptor piece, nitrogen lines and current connectors. Insulative feedthroughs electrically isolate the heat interceptor module from the fluid circuit.*

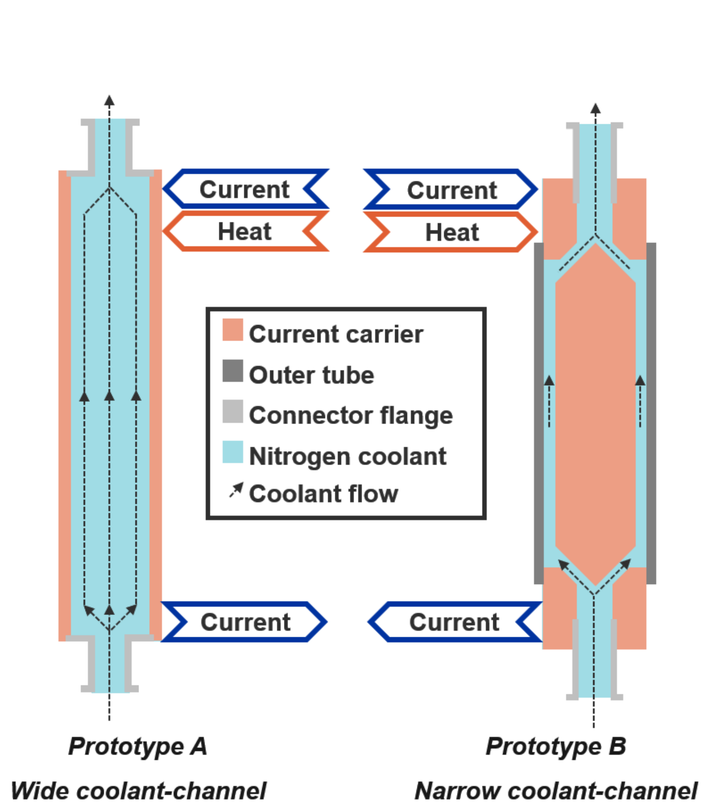


***Fig.2** – Conceptual designs showing cross-sections and coolant paths.*

***Fig. 3** – Photographic images of heat interceptors before and after assembly.*

Prototype Manufacturing & Testing

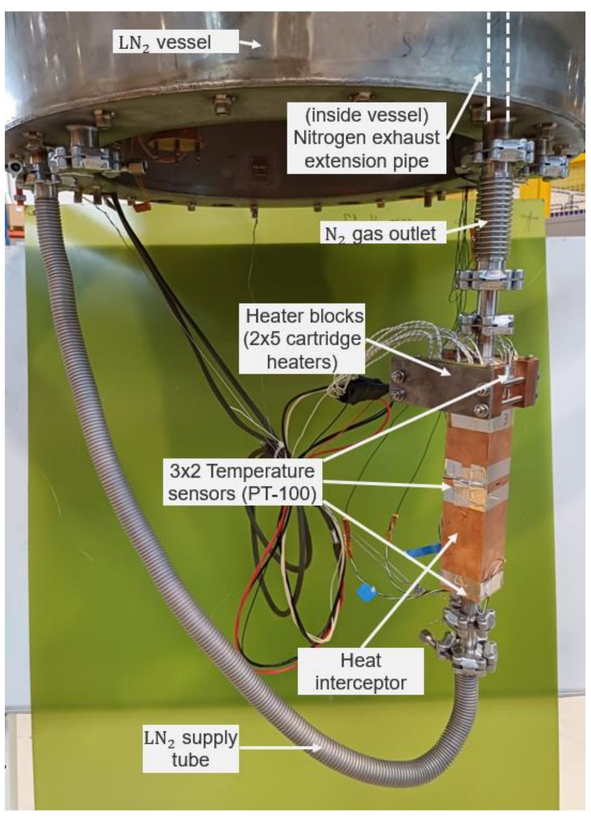


***Fig. 4** – Experimental cooling capacity setup with heater blocks to simulate top heat loads and temperature sensors (PT-100) to measure thermal response. Image shows setup for prototype A, the setup for prototype B is similar.*

Two heat interceptor prototypes:
'A': Wide, 40 mm coolant channel;
'B': Thin, 2 mm annular channel;
→ study effect of hydraulic diameter. Other parameters (copper cross-section and boiling area) were identical or similar.
Both have copper main conductor. Steel flanges/outer tube joined by brazing (Fig. 3).

Cooling capacity experiments

- Heaters may simulate current lead heat load effect relatively well up to several kA (supported by modelling).
- Heater blocks used to estimate cooling capacity.

Cooling capacity (CC):
- Max. Q_{top} for which $T_{bot} < 79\ K$

- Into 10 mbar cryostat; LN_2 vessel filled.
- Temperature sensors to monitor performance.

Results & Discussion

Heating power was increased stepwise, with stabilization for every step (Fig. 5). We observed gradual increase in temperature below CC and sharper increase above CC (Fig. 6).

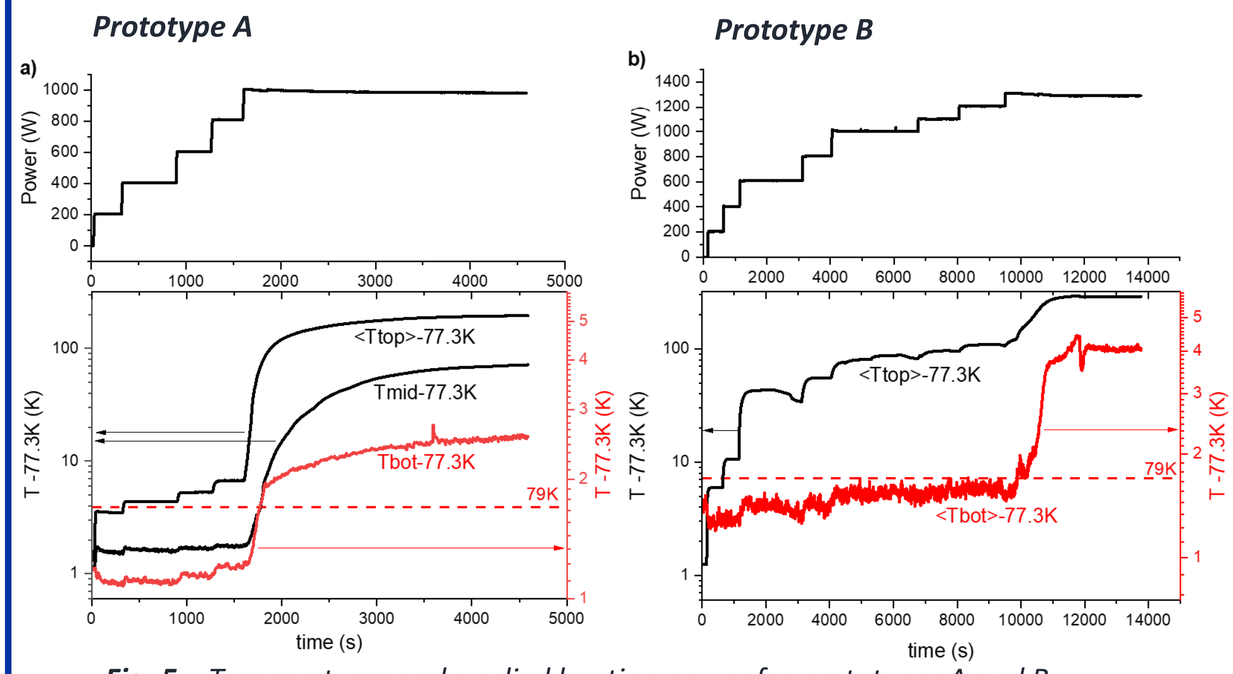
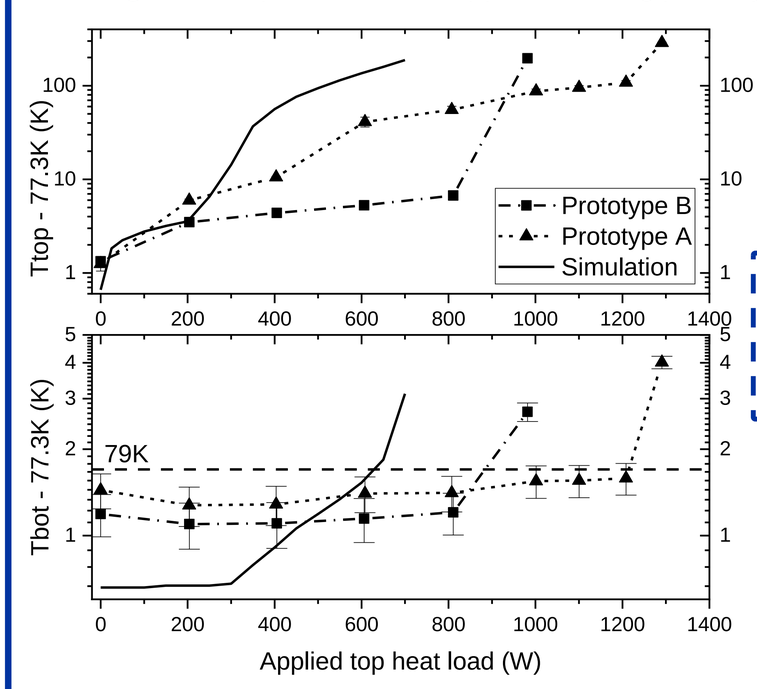


***Fig. 5** – Temperatures and applied heating power for prototypes A and B.*



$$Q_{max,A} = 0.90 \pm 0.09\ kW$$

$$Q_{max,B} = 1.25 \pm 0.05\ kW$$

***Fig. 6** – Average stable top- and bottom temperatures versus top heating power.*

- Experimental prototypes showed higher CC than simulation based on data [2] on pool boiling.
- Some temperature oscillations were observed after refilling supply vessel but mostly stable. Likely due to change in supply vessel flow patterns and increased thermosyphon driving force.
- Prototype A's lower CC and sharp transition were potentially due to inhibiting effect of film boiling that is less pronounced in B's more turbulent flow.
- Comparison to simulation showed that effect of current on temperature is small <5 kA. For higher currents, large copper cross-section may be used.

Conclusion & Outlook

- Both developed prototypes prove **powerful** enough for multi-kA current lead heat interception **with relatively simple designs**.
- Prototype B has a higher cooling capacity and A is simpler to manufacture.
- Modularity allows attachment of varying current leads, **ideal for simple/ cheap R&D cryocooler rigs** having different current requirements per test setup.
- Current lead heat interceptor for **large superconducting magnet current leads such as BabyIAXO and ATLAS** may be beneficial as easy-to-use cooling system. A small LN_2 Dewar gives enough cooling during cryogenic plant downtime.

Acknowledgements

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References

[1] Ekin, J. *Experimental techniques for Low-Temperature Measurements. 2006*
[2] Cowley et al. *A method for improving heat transfer to a boiling fluid. 1962*