CRYOGENIC PULSATING HEAT PIPES: APPLICATION TO HTS COILS

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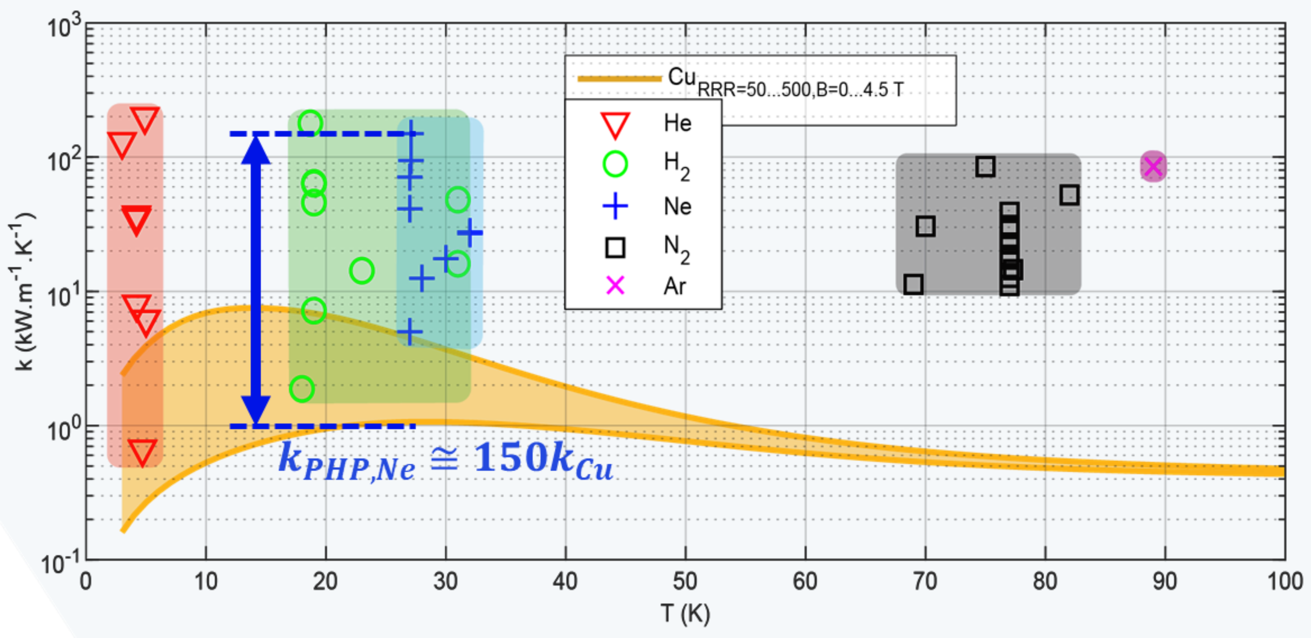
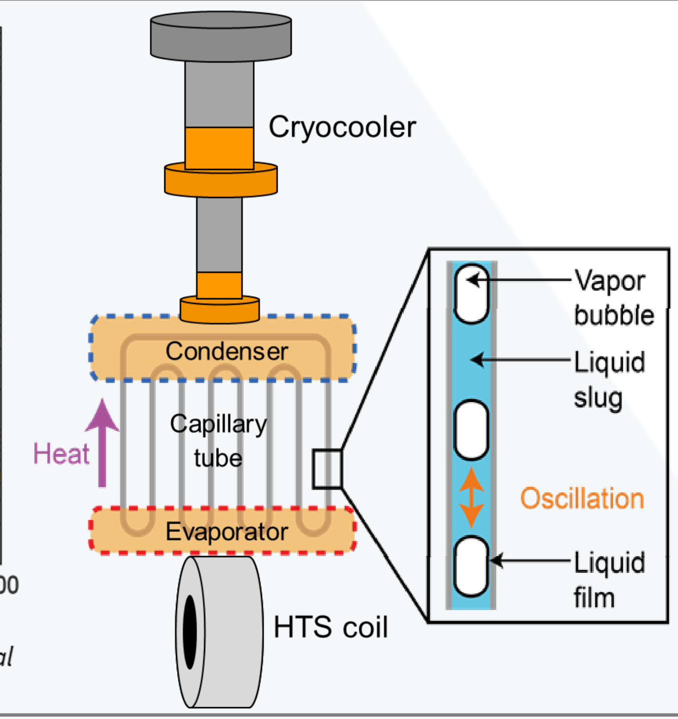
Context

- **Cryocoolers** are increasingly favored **for cooling superconducting components** and an efficient **heat transfer** between both **is crucial for ensuring the thermal stability** of the superconductor
- **VDL ETG and PSI** develop an **efficient and passive thermal link for cryogenic systems** used in accelerators, gantries, space, and industrial applications
- **Aim of the study:** Design, model, build, test and apply **Pulsating Heat Pipes (PHPs)** to **cryocooler-based HTS coil**



Maximum effective thermal conductivity of different PHPs from literature and comparison to copper thermal conductivity against temperature

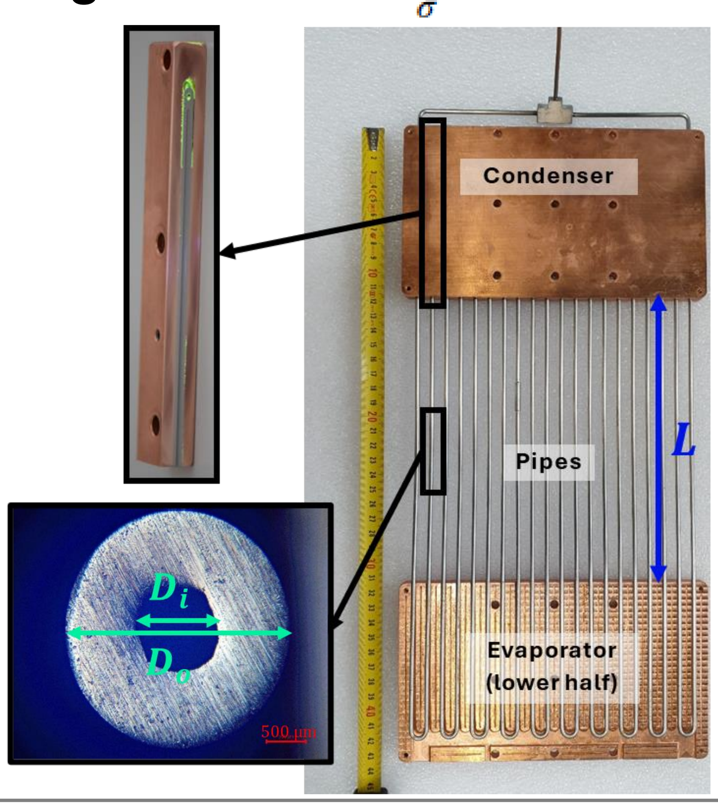


Pulsating Heat Pipes

Principle: Transfer heat from an evaporator to a condenser using thermally driven two-phase flow

Gain: on thermal resistance, weight and bulk, possibility to operate without gravity and to be used as thermal switch

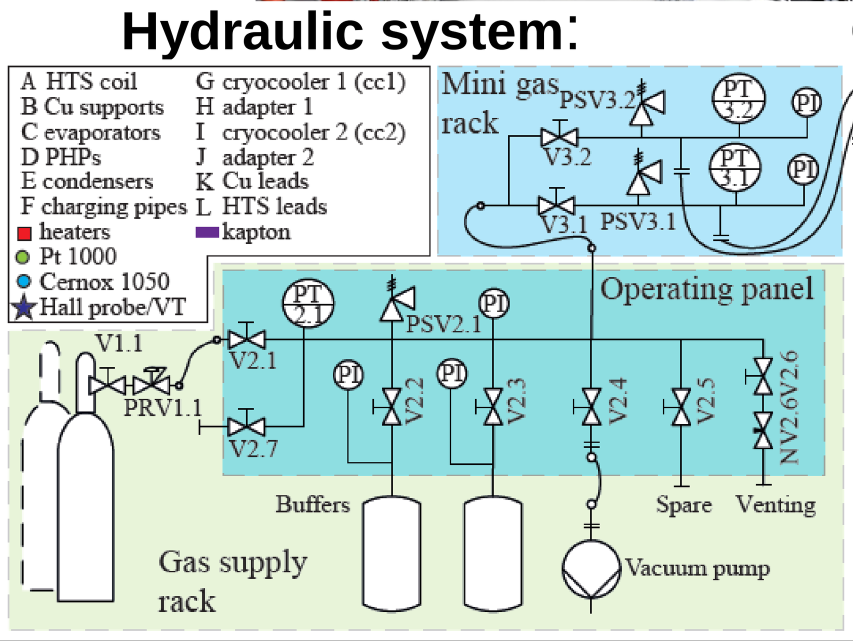
Design: $Bo = \frac{g(\rho_l - \rho_v)D^2_{crit}}{\sigma}$



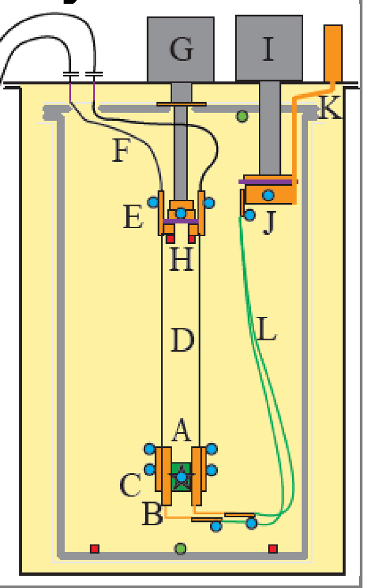
Experimental Setup

Testing facility:

Hydraulic system:

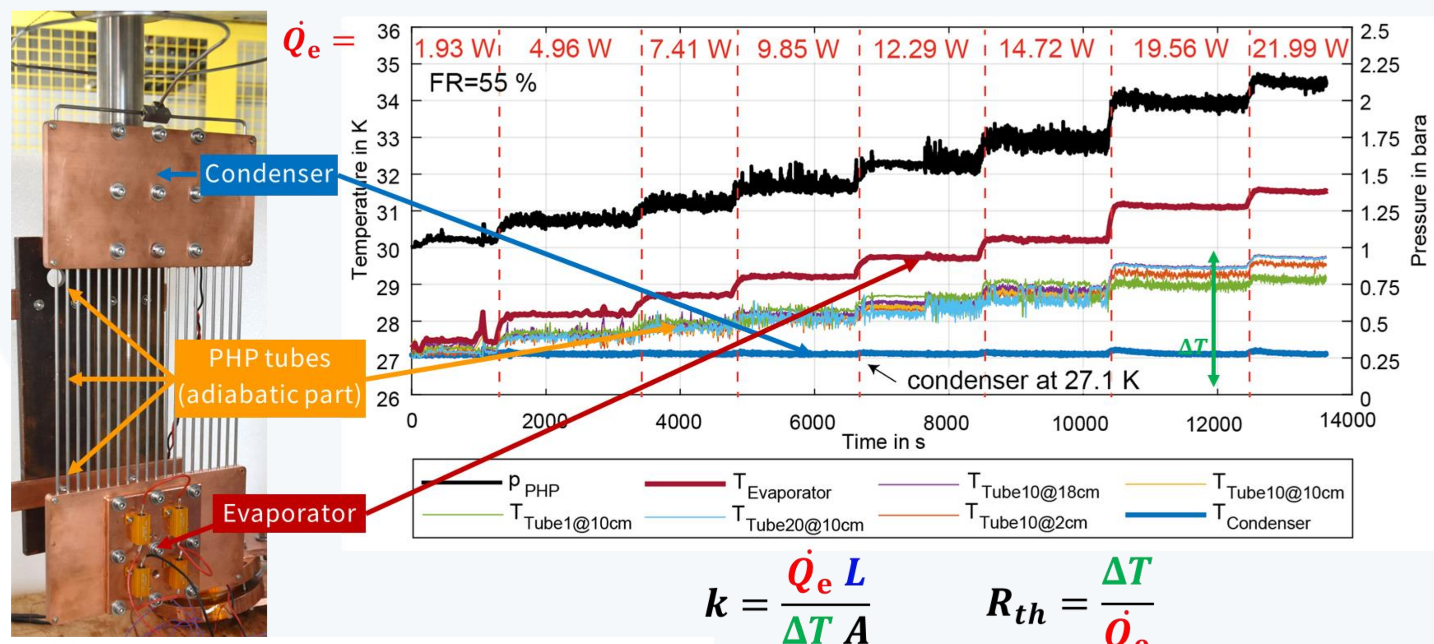


Cryostat:

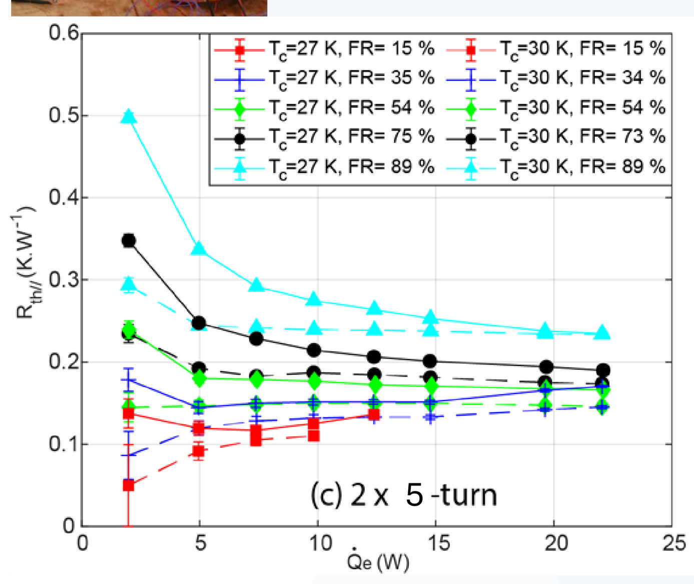


Characterization

Experiments: Step-wise heating mode



$k = \frac{\dot{Q}_e L}{\Delta T\, A}$ $R_{th} = \frac{\Delta T}{\dot{Q}_e}$

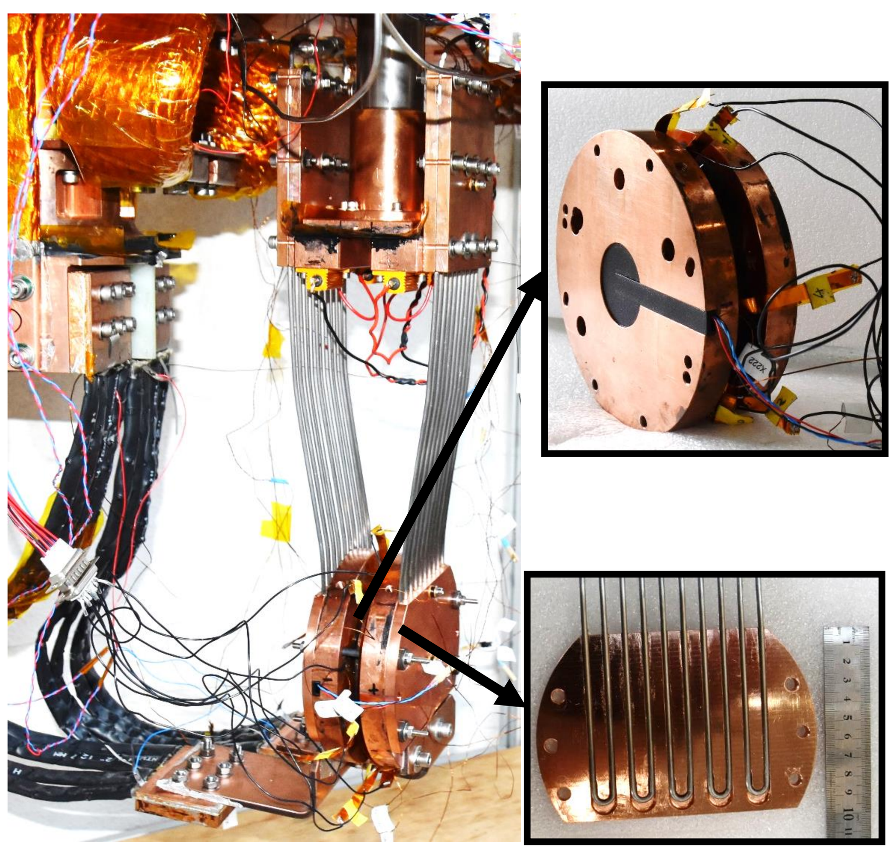


Parametric study:

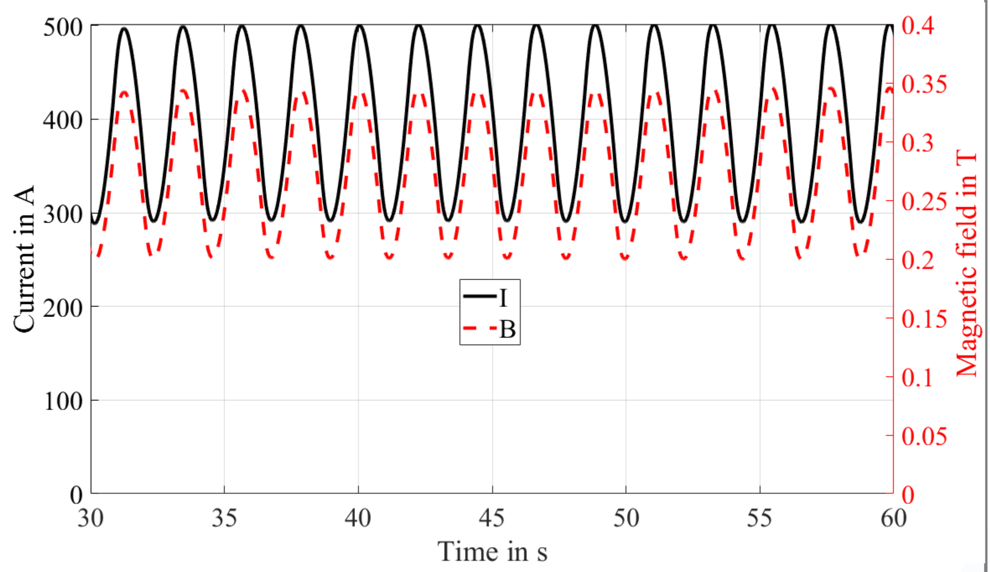
- Effect of heat load, liquid volume fraction (filling ratio), condenser temperature and number of turns on thermal resistance
- Optimal parameters identified
- Dry-out conditions identified
- Correlations determined

Application to an insulated HTS coil

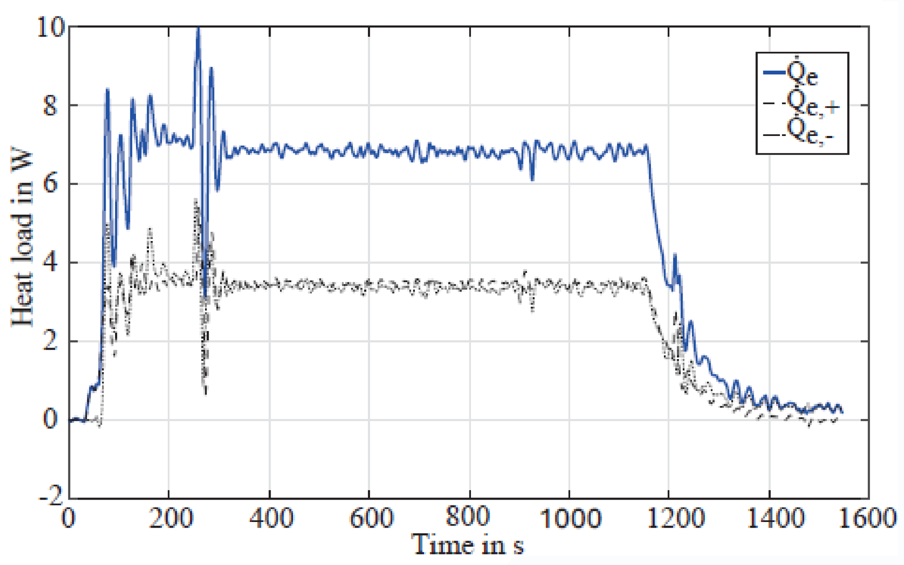
PHPs and HTS coil assembly:



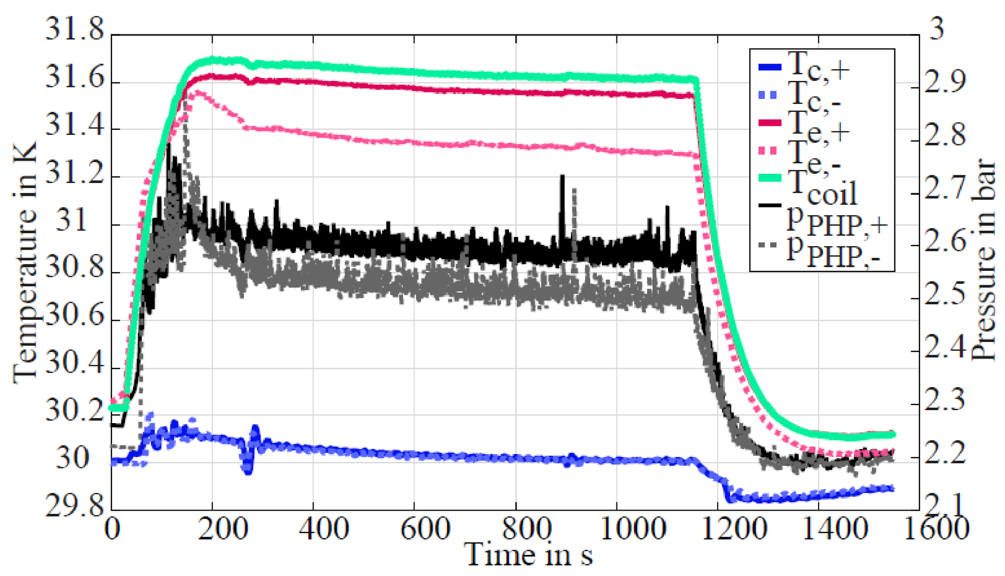
Alternative current (AC) operation:



Heat load from AC losses:



Temperatures and pressures:



Comparison to copper rod:
The thermal resistance of the copper rod is calculated to be nearly 1.03 K/W using:

$$R_{th,calc} = \frac{L_a}{k_{Cu}\frac{n\pi D_o^2}{4}} = \frac{T_{coil,calc} - T_c}{\dot{Q}_e}$$

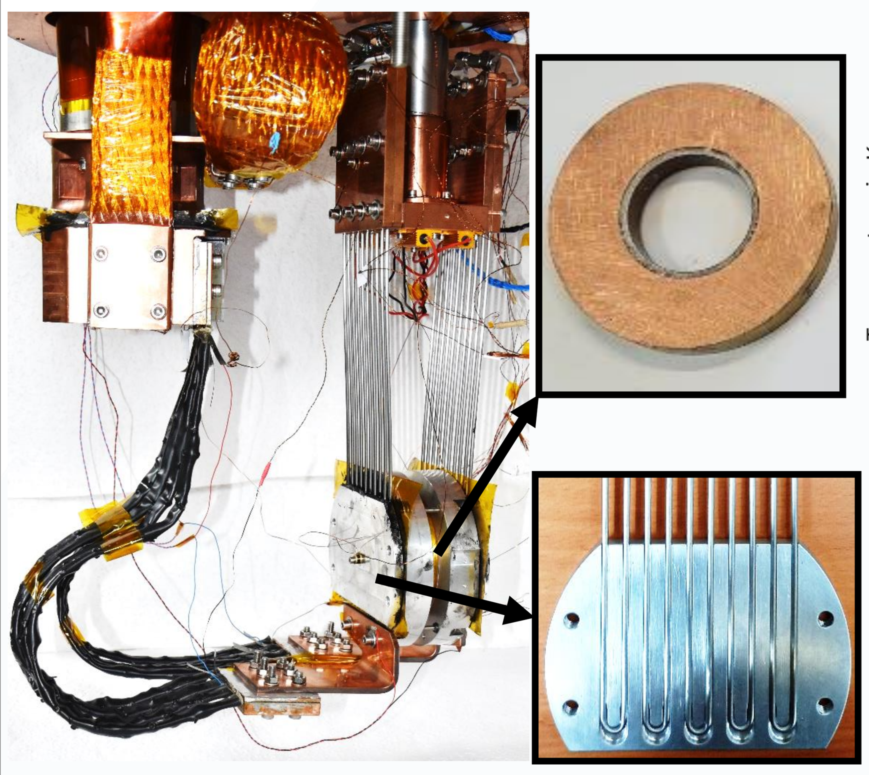
The use of two PHPs in parallel **reduces the thermal resistance by nearly $r \cong 80\%$** across the four experiments:

SUMMARY OF THE RESULTS.

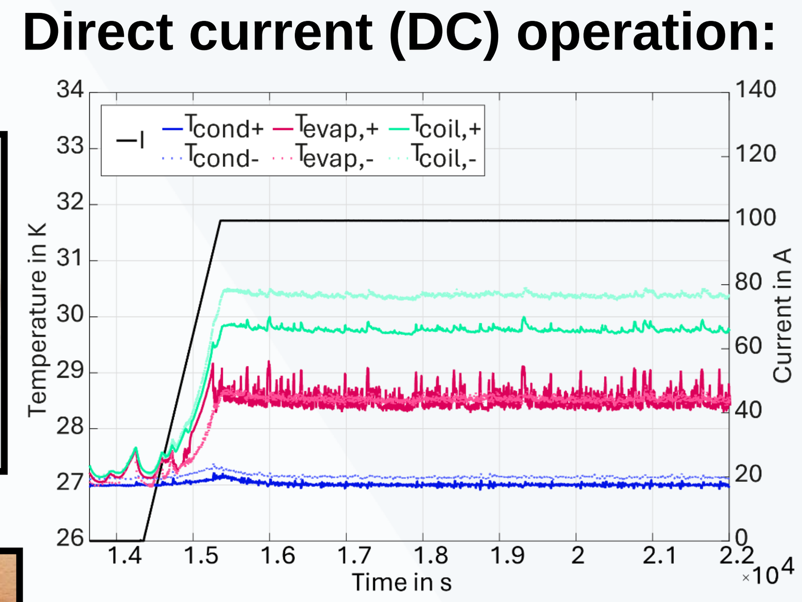
T_c (K)	FR (%)	$R_{th,//}$ (K/W)	T_{coil} (K)	$T_{coil,calc}$ (K)	r (%)
27.03	37	0.21	28.45	33.32	79
27.02	56	0.24	28.74	33.38	76
30.00	40	0.18	31.32	37.05	82
30.03	55	0.20	31.64	37.15	80

Application to a non-insulated HTS coil

PHPs and HTS coil assembly:



Direct current (DC) operation:



PHPs operated well:
$\Delta T_{cond \to evap} = 1.5$ K
$k_{eff} = 103$ kW/(m · K)
$R_{th,//} = 0.13$ K/W

1st test: large $\dot{Q}_e = 12.1$ W due to high resistance of aluminum supports

2nd test: high purity copper supports led to $\dot{Q}_e < 1$ W, PHPs cooled the coil, but not enough heat load to start the oscillating flow in the tested current range

Conclusion

- **Neon PHPs** designed and manufactured
- Experimental setup dedicated to PHP **characterizations** and **applications** built at PSI
- Characterization campaigns were used to define **optimal parameters** and correlations for predicting their performance
- **Two neon PHPs in parallel were operated simultaneously** with the evaporators integrated into the coil supports
- **Thermal resistance reduction of nearly 80%** compared to a copper rod of the same adiabatic length and cross-section
- **First PHP application**, to our knowledge, **to cool and operate** cryocooler-based insulated and non-insulated **HTS coils**

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