Nitrogen-based Pulsating Heat Pipes with Varied Configurations

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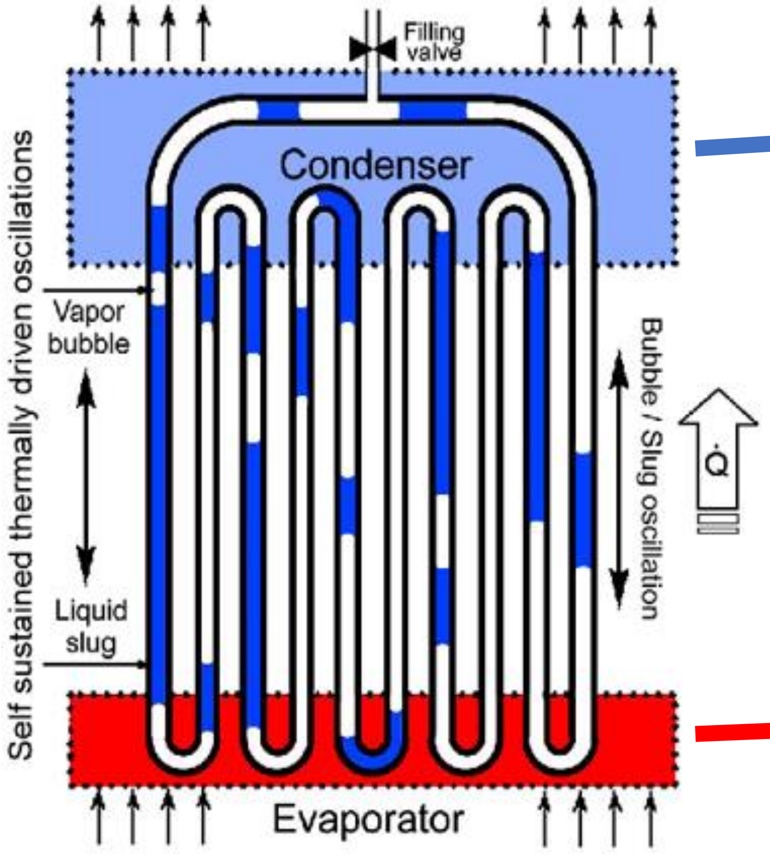
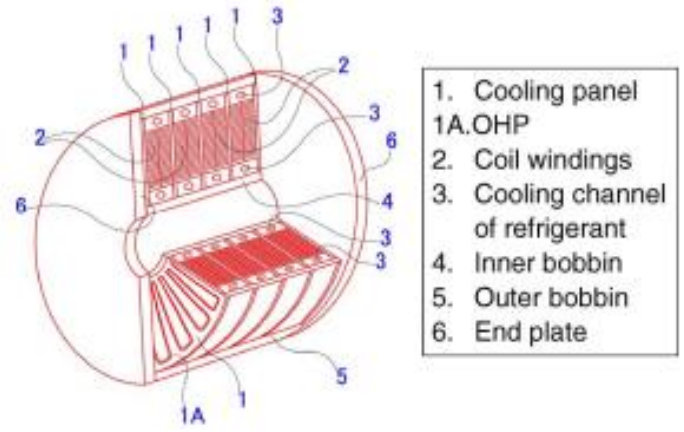
What is a Pulsating Heat Pipe



Schematic of a Pulsating Heat Pipes (PHP) [1]

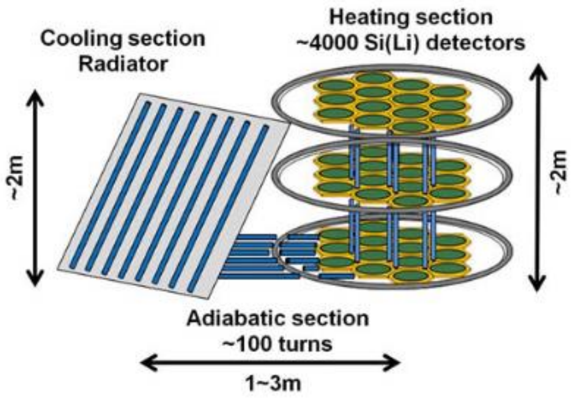
- When the vapor bubble flows into the condenser section, it condenses into liquid resulting in a pressure decrease.
- When heat is applied on the evaporator, the pressure of the vapor plug is increased.
- The increased vapor pressure helps the fluid overcomes the capillary forces, gravitational forces.

Application

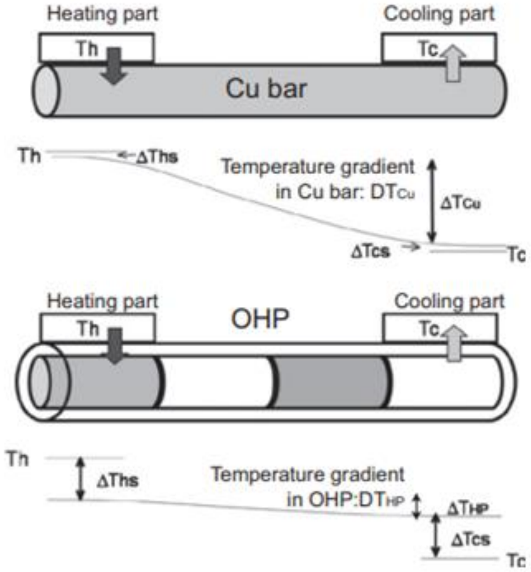


The PHP embedded in the HTS magnet [2]

MRI

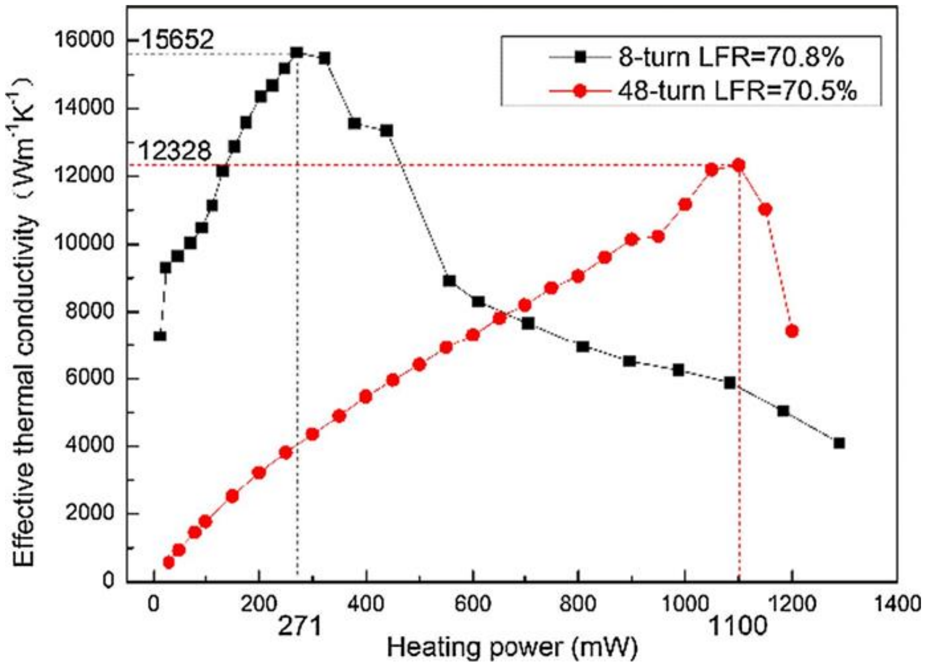


The PHP prototype cools down the spectrometer



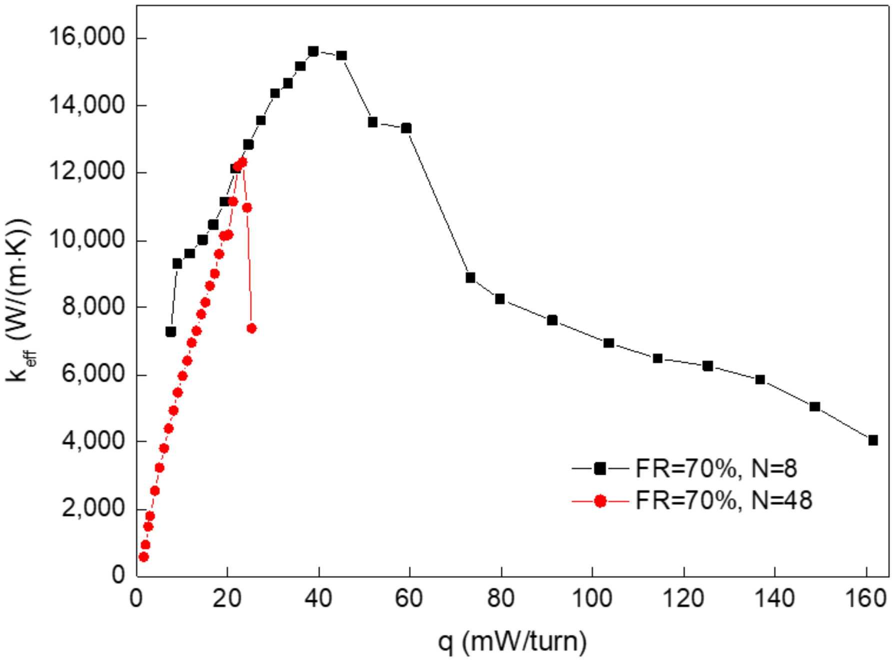
PHP has a much lower ΔT[3]

Motivation



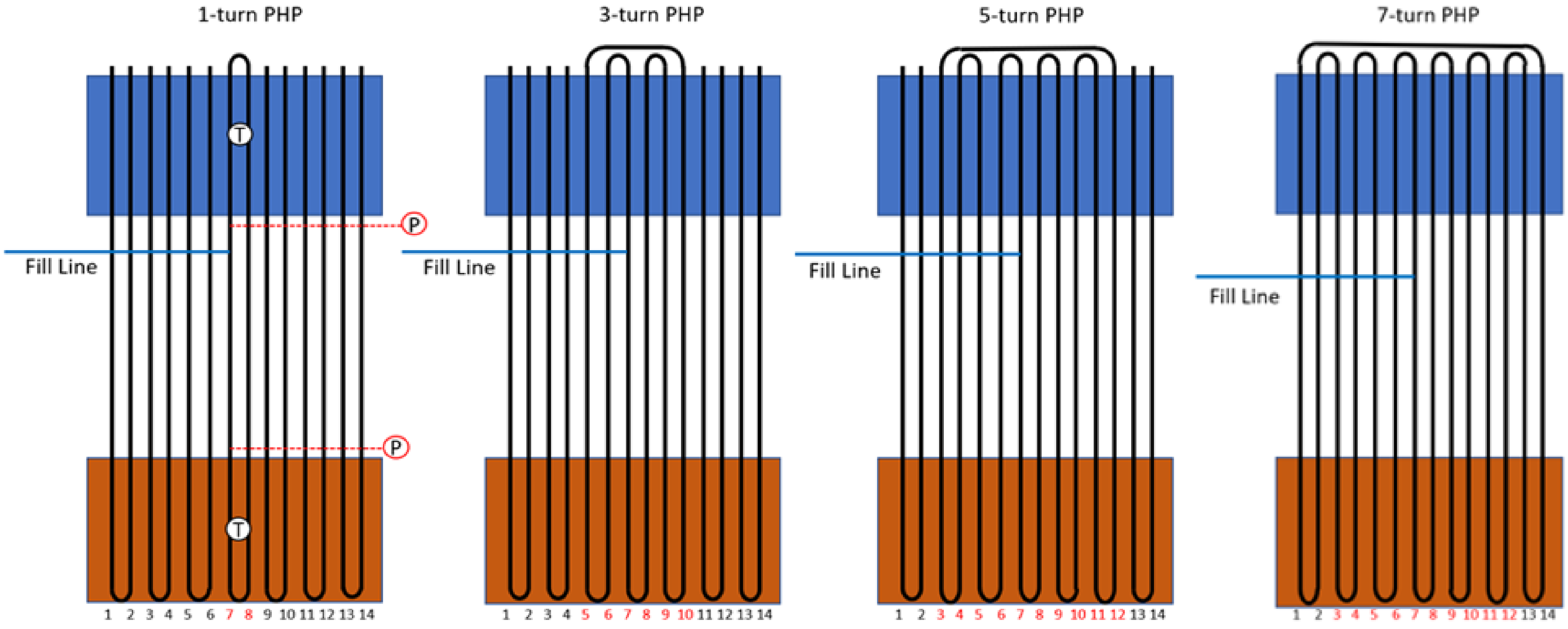
PHP with a small number of turns has good thermal performance at a lower heat load while a PHP with a large number of turns has a good heat transfer performance at a higher heat load.

The x-axis is in terms of head load per turn



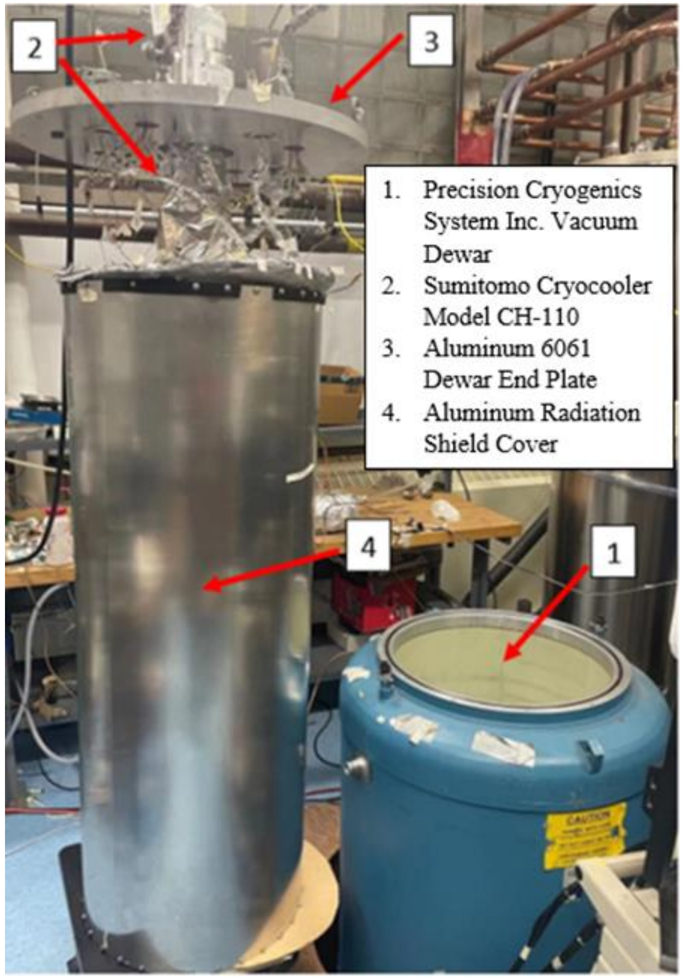
Although 48-turn can achieve maximum heat capacity at 1200[mW], but if we split 1200[mW] on a total of 48 turns, each turn only takes around 25[mW].

Motivation

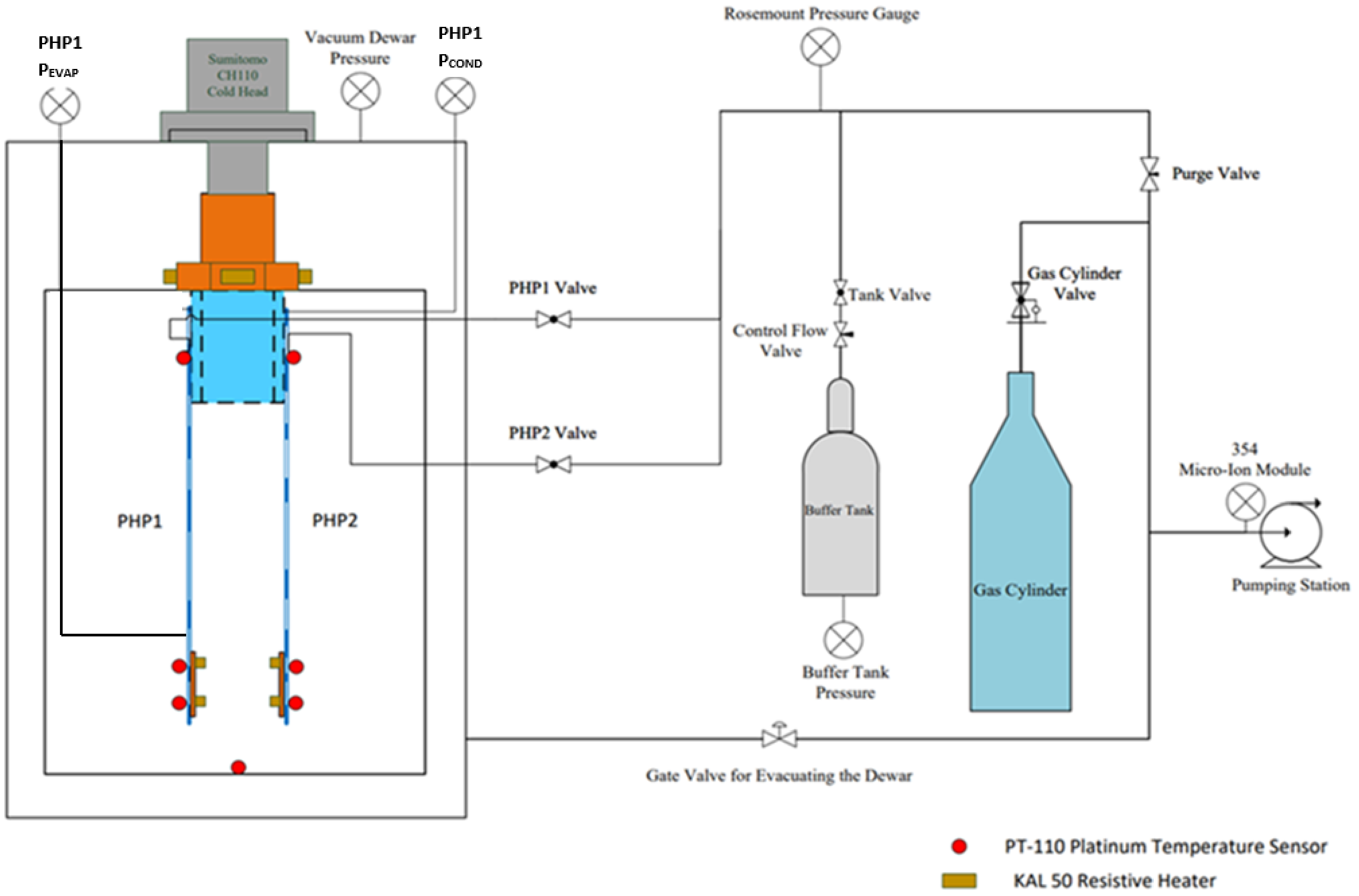


The number of turns of my PHP can change from 1 to 3 to 5 and 7 turns. With this design, we will be able to determine the optimal heat transfer per turn for a nitrogen PHP.

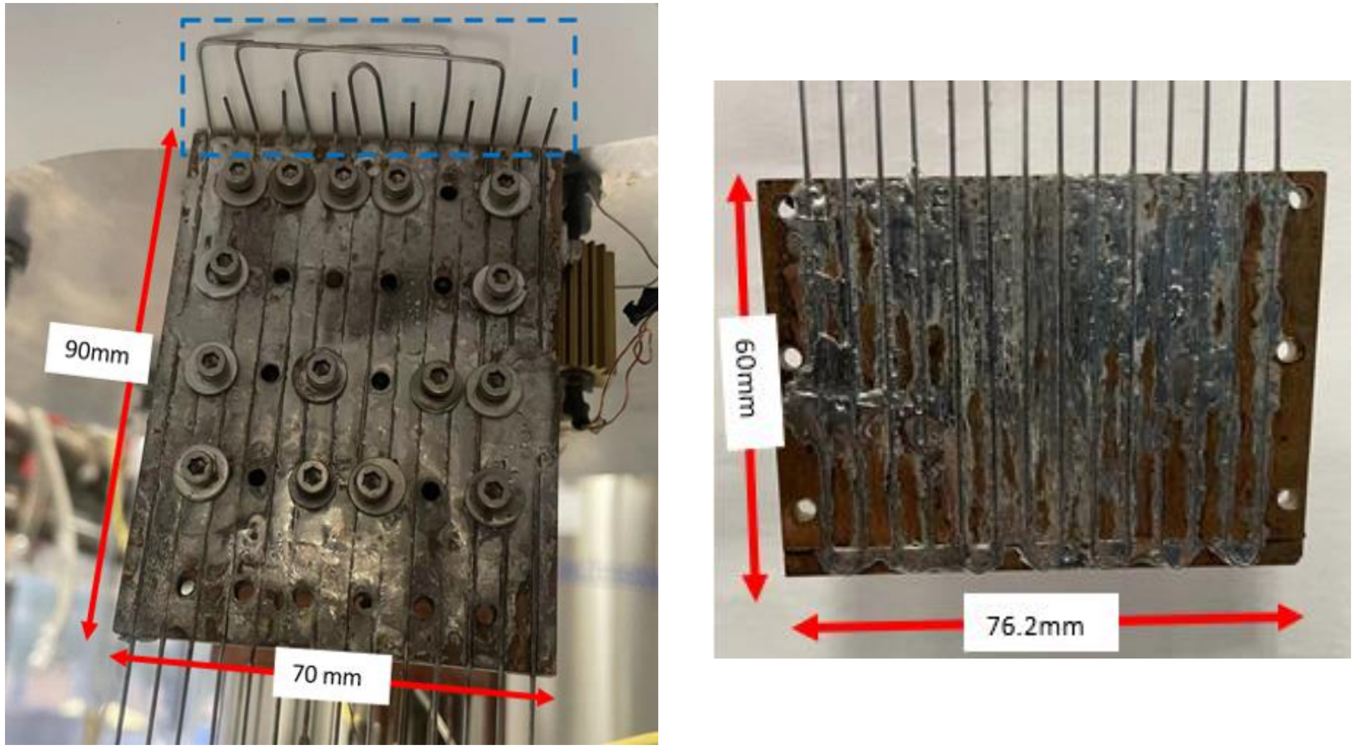
Experimental Setup



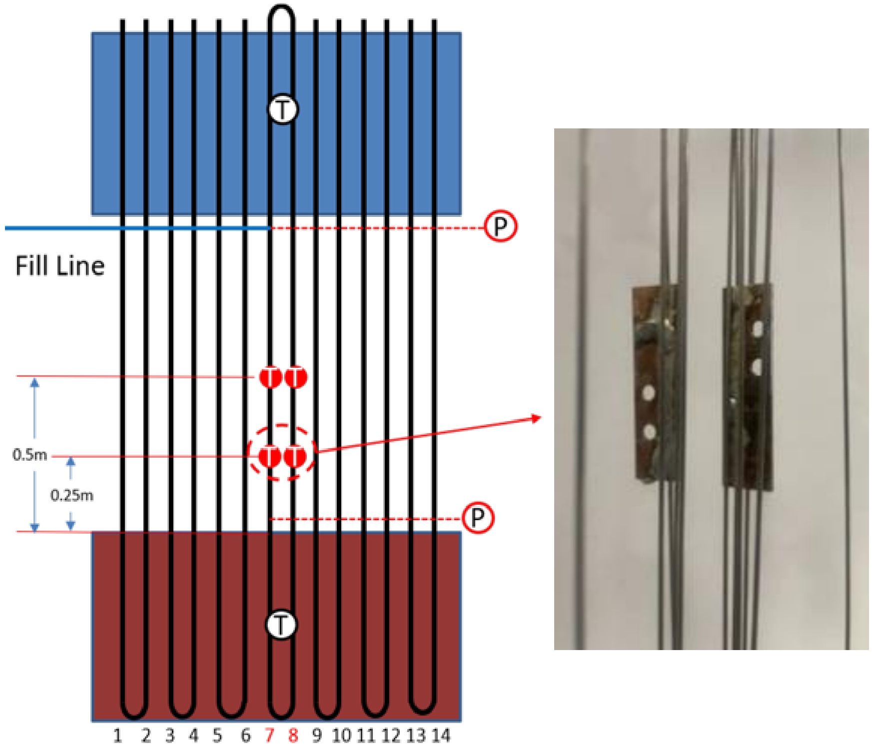
1. Precision Cryogenics System Inc. Vacuum Dewar
2. Sumitomo Cryocooler Model CH-110
3. Aluminum 6061 Dewar End Plate
4. Aluminum Radiation Shield Cover



Experimental Setup



The Condenser (left) and Evaporator (right) sections



Locations of PRTs on each PHP are marked as ‘T’ and the locations of the pressure sensors are marked as ‘P’ in the schematic. Only PHP1 has pressure transducers installed.The locations

- The adiabatic section between the condenser and evaporator is 1m.
- The capillary tube is made from 304 stainless steel with an I.D. of 0.5mm and an O.D. of 0.8mm.

Experimental Conditions

Experimental Test	T_{cond} [K]	Initial Fill Ratio [%]
1	84.5	50
2	84.5	63
3	84.5	75
4	77.4	50
5	77.4	63
6	77.4	75

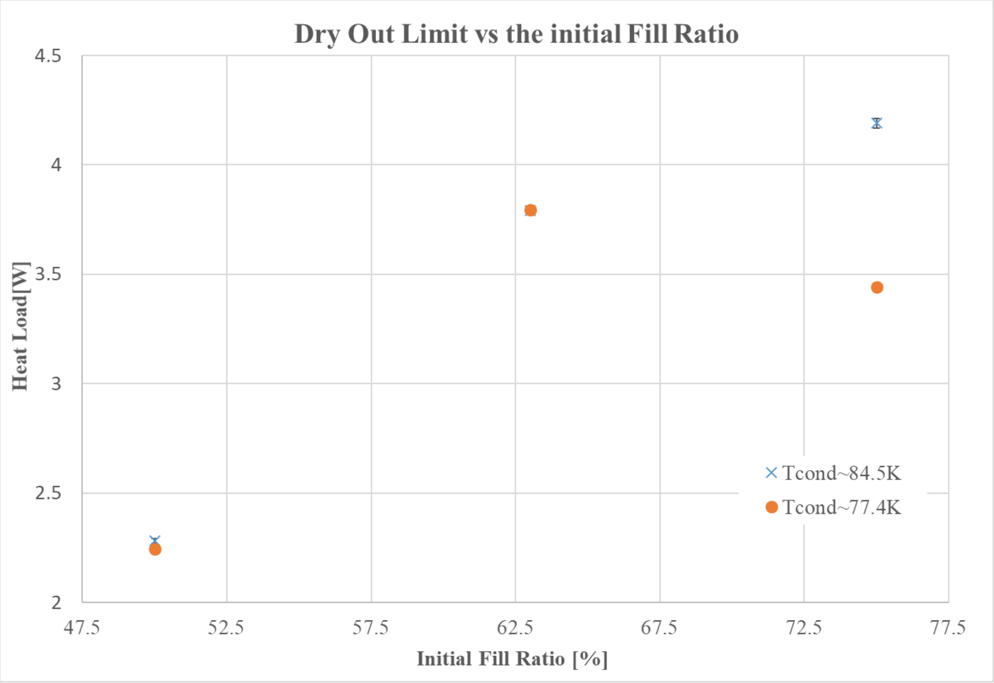
Fill Ratio: $FR = {}^{Vol_{liquid}}\!/_{Vol_{PHP}}$

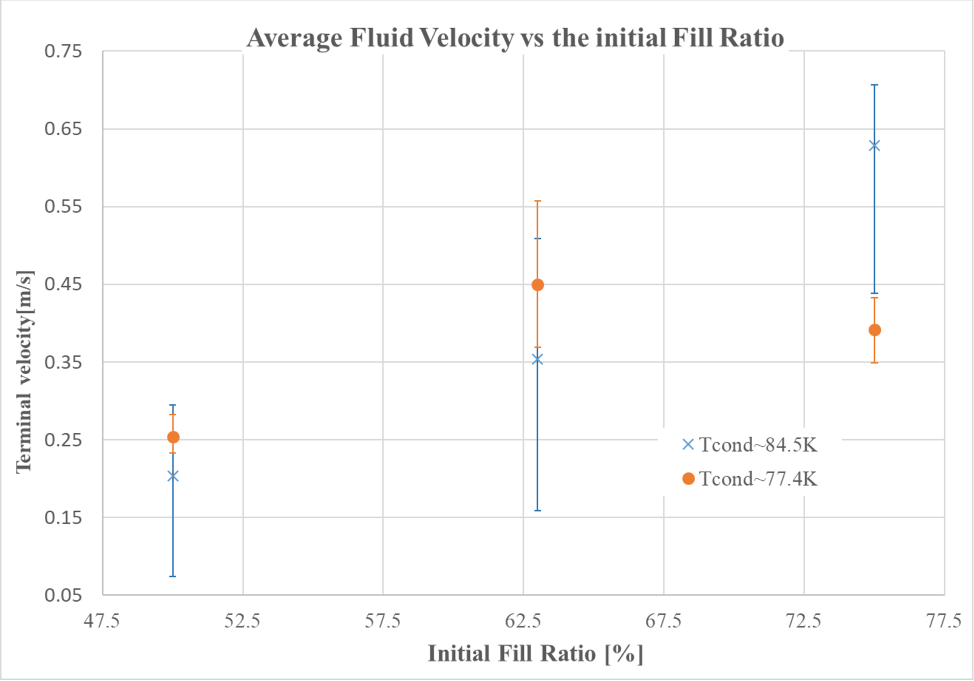
A total of six experimental tests have been conducted on the PHP with two different condenser temperatures and three different fill ratios.

The heat transfer performance of the PHP is evaluated by the effective thermal conductivity:

$$k_{eff} = \frac{QL}{NA_c(\bar{T}_e - \bar{T}_c)}$$

Experimental Results

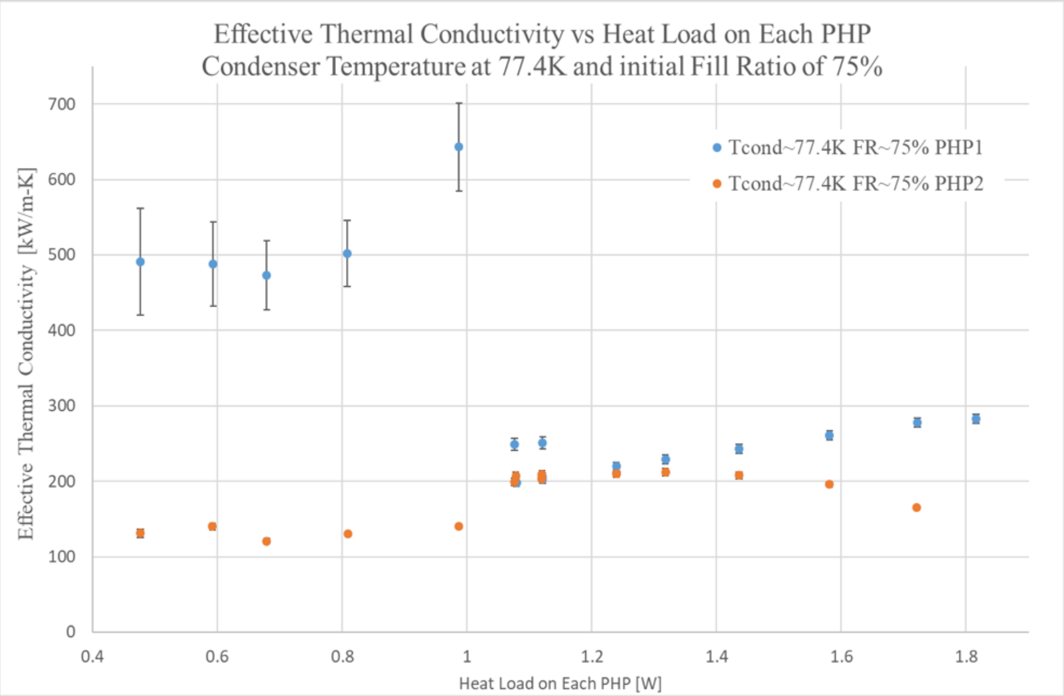


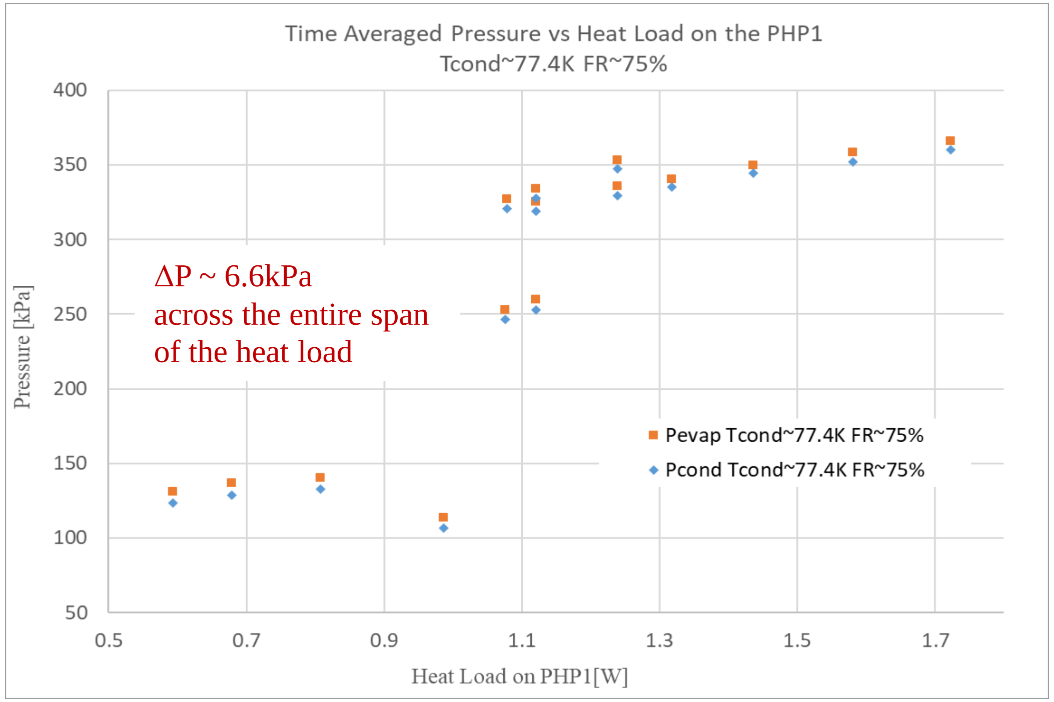


- The maximum dry-out limit of the PHP assembly is observed at 4.19 W of total heat load at the condenser temperature of 84.5 K and the initial fill ratio of 75%
- The optimal effective thermal conductivity of PHP1 is 1,048,000 W/m-K when 0.81 W is applied on each PHP (a total of 1.62 W on the PHP assembly) at the condenser temperature of 84.5 K and the initial fill ratio of 63%.
- The optimal effective thermal conductivity of PHP2 is 838000 W/m-K when 1.32 W is applied on each PHP (a total of 2.64 W on the PHP assembly) at the condenser temperature of 84.5 K and the initial fill ratio of 63%..

Experimental Results

Condenser temperature of 77.4K and initial Fill Ratio of 75%



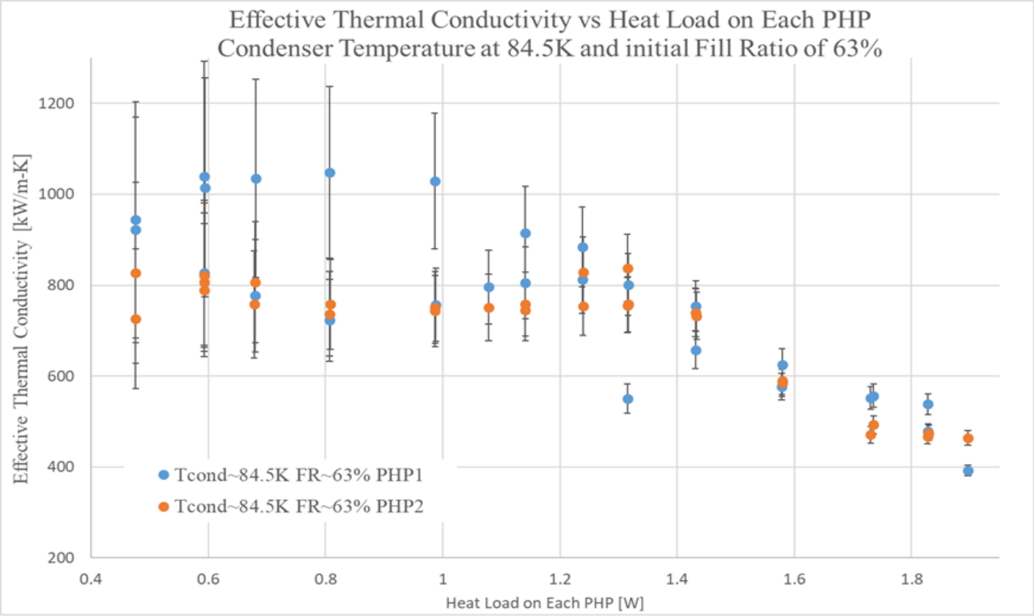


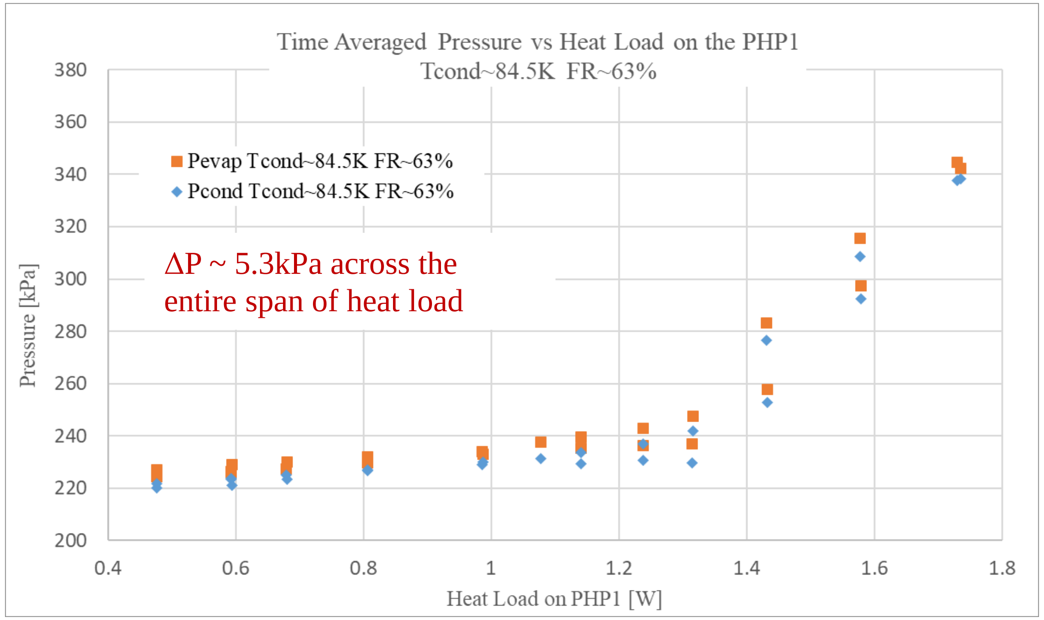
ΔP ~ 6.6kPa
across the entire span
of the heat load

- The PHP reaches dry-out and is then re-booted at the heat load of 1.08 W for each PHP.
- In the reboot run, both PHP subsections can operate with the heat load on each PHP from 1.08 W to 1.72 W. PHP2 dries out at a heat load of 1.82 W.
- After the reboot, the difference in the effective thermal conductivity between PHP1 and PHP2 is much smaller. Between 1.08 W and 1.32 W, the percentage difference is less than 10%.

Experimental Results

Condenser temperature of 84.5K and initial Fill Ratio of 63%





ΔP ~ 5.3kPa across the entire span of heat load

- PHP1 exhibited dry-out behavior and rebooted at both 1.32 W and 1.43 W on each PHP.
- After the dry-out limit was reached, various experiment runs at heat load levels of 0.48 W, 0.60 W, 0.68 W, 0.81 W, 0.99 W, 1.32 W, 1.43 W, and 1.73 W were repeated.
- The difference in the time-averaged mean pressure between the original and repeated runs is insignificant, even though the difference in effective thermal conductivity of PHP1 is significant.

Summary

- The maximum dry-out limit of the PHP assembly is observed at 4.19W of total heat load at the condenser temperature of 84.5K and initial FR of 75%

- PHP subsection dries out at moderate heat load but can be rebooted with continued performance to higher heat loads.

- The effective thermal conductivity of the PHP subsection differs drastically before and after the reboot process.

- Gradual increase in the overall system pressure is observed in the FR of 50% and 63% fill ratio tests. The huge leap in the overall system pressure after the PHP reboot is observed in the 75% fill ratio runs.

- For future measurements, the PHP test rig will be modified to operate with 3-turn, 5-turn, and 7-turn PHPs in the parallel configuration but using the same condenser temperature and fill ratio conditions as with the single-turn PHP.

Thank You

Any Question?

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References

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[2] K. Natsume, K. Mito, N. Yanagi and H. Tamura, "Development of a flat-plate cryogenic oscillating heat pipe for improving HTS Magnet Cooling," Physics Procedia, vol. 45, pp. 233-236, 2013.

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[4] Li, Monan, Laifeng Li, and Dong Xu. "Effect of number of turns and configurations on the heat transfer performance of helium cryogenic pulsating heat pipe." *Cryogenics* 96 (2018): 159-165.