DE LA RECHERCHE À L'INDUSTRIE

Thermal performances of a meter-scale cryogenic pulsating heat pipe

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OUTLINE

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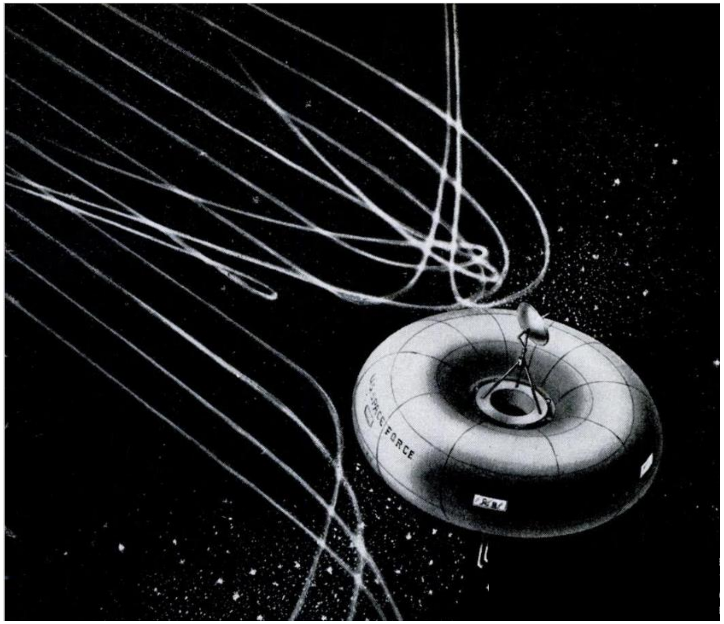
- PHP Experiment
  - PHP design
  - Facility design
- Experimental results
  - General thermal behavior
  - Low heat fluxes
  - High heat fluxes
  - External tube
- Others experiments
- Conclusion

CONTEXTE



The SR2S project :

Protect the astronauts from solar and galactic cosmic radiation using MgB_2 **superconducting magnet** around the human habitat

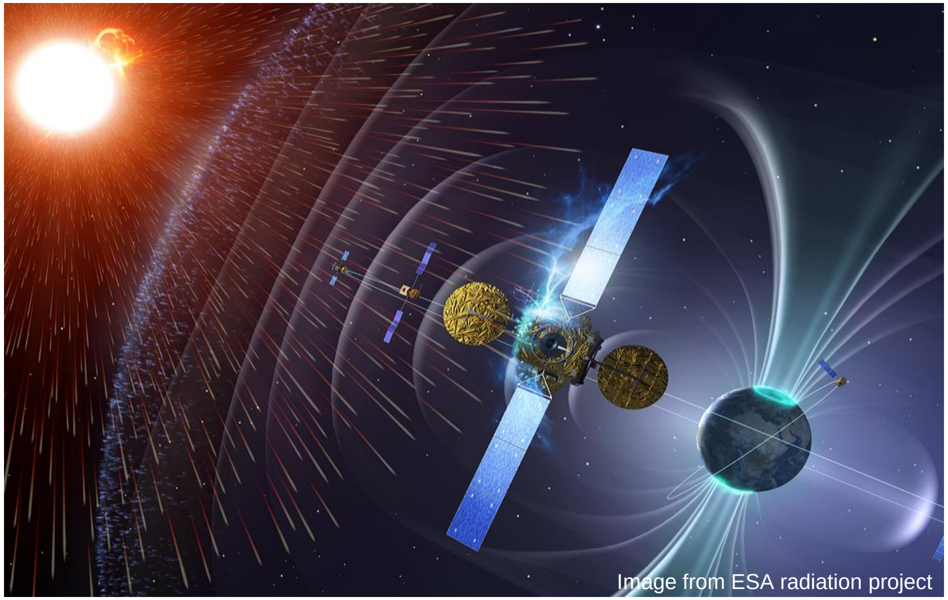
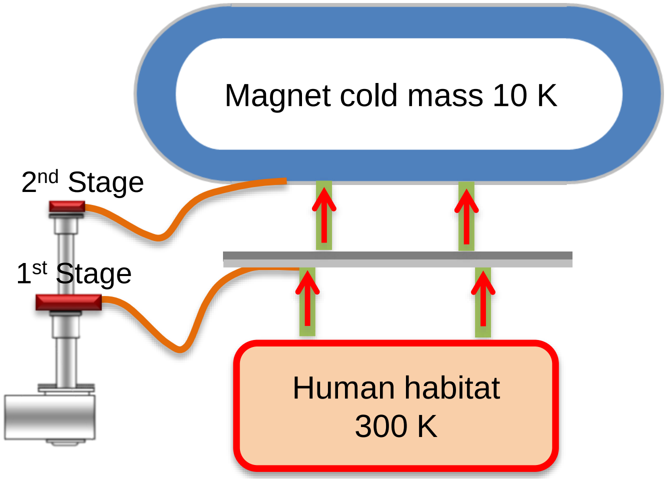


Image from ESA radiation project

Objective :

Design the most efficient system to cool down this magnet during at least 2 years

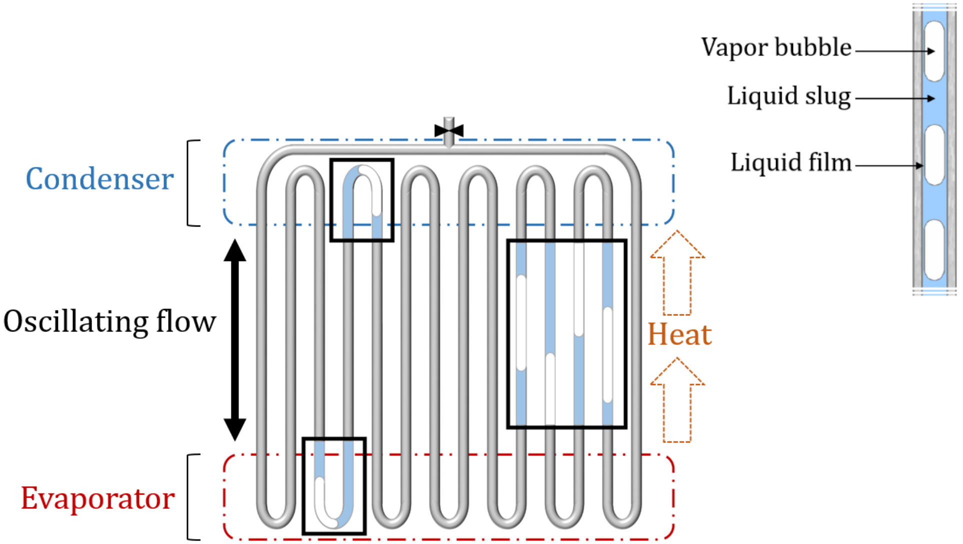
Pulsating Heat Pipe (PHP)



Cooling system combining **cryocooler** and **Pulsating Heat Pipe (PHP)**

- No liquid bath
- Compact cryogenic system
- Long duration system

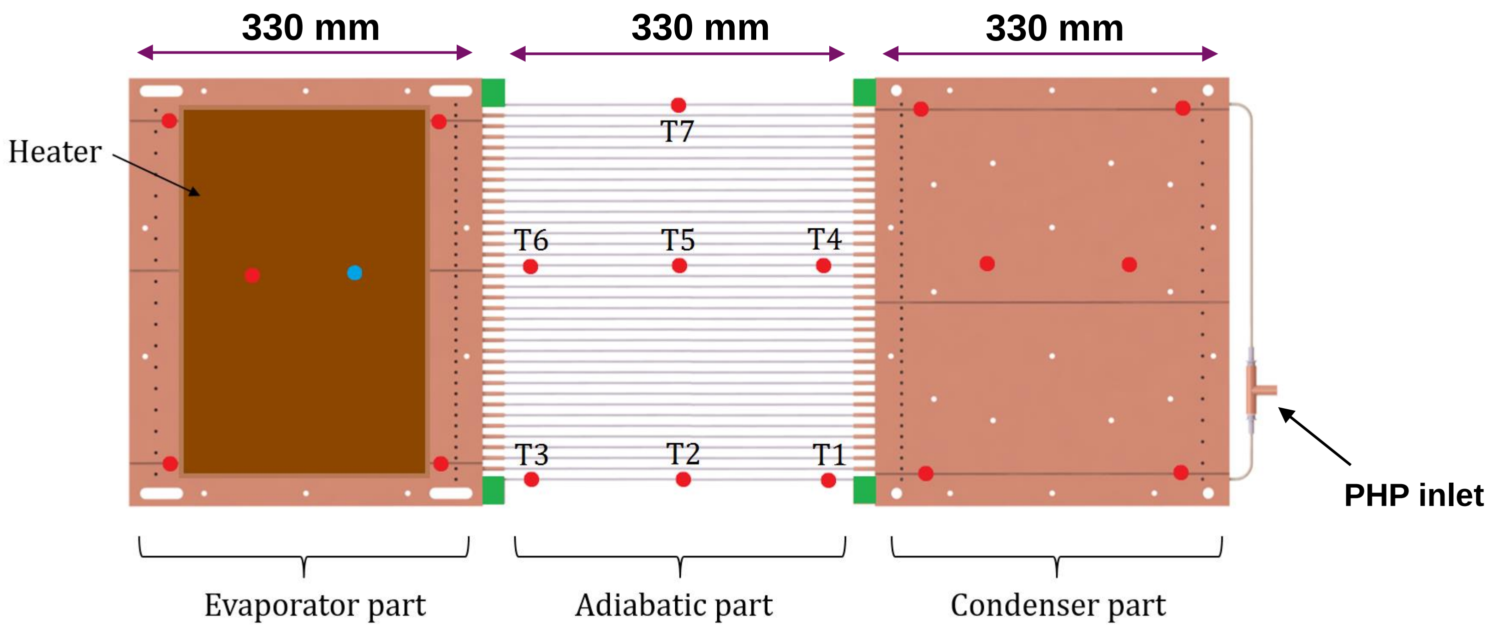
A **PHP** is a small tube without wick structure partially filled with a working fluid and arranged in many turns



This system works :

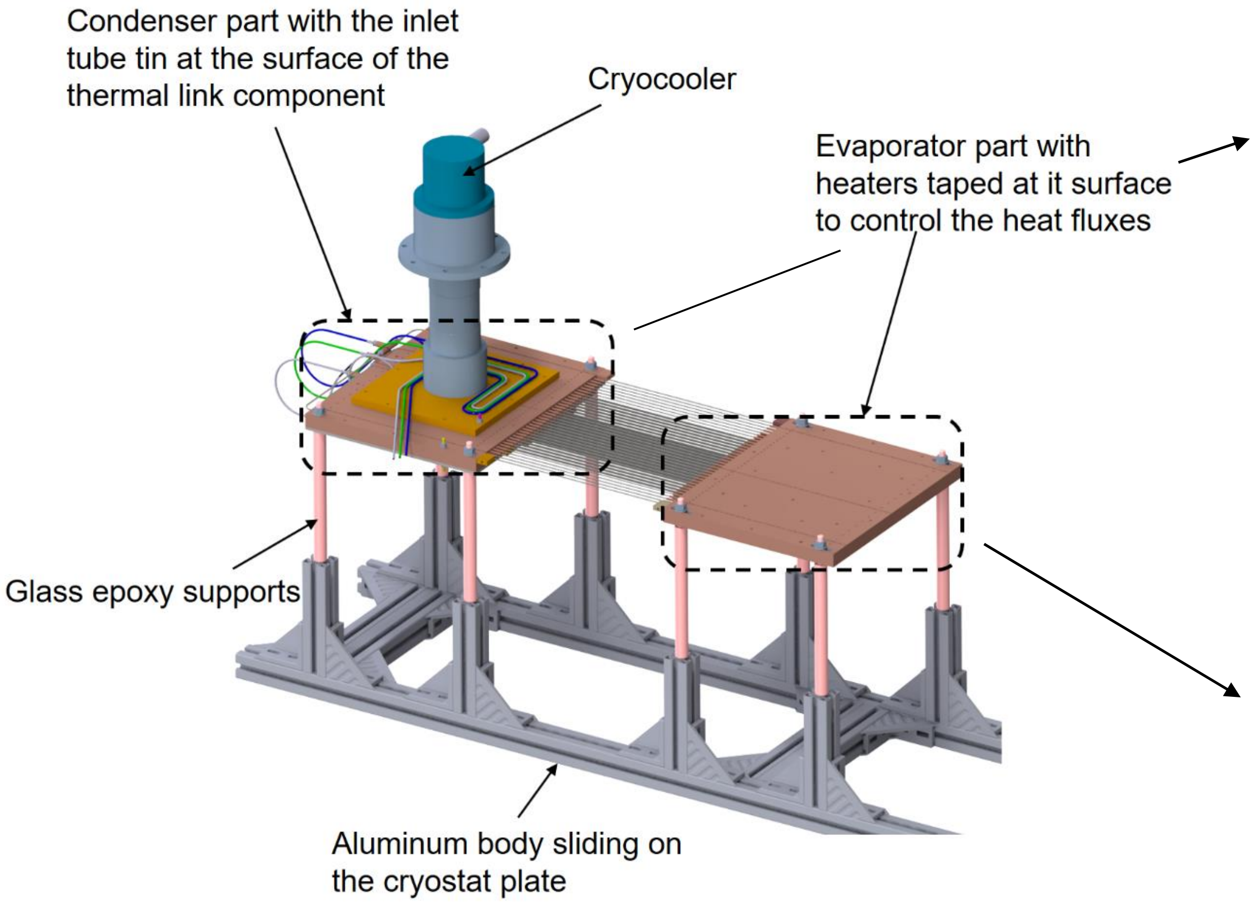
- Without gravity
- Having a long distance between the condenser and the evaporator (out of the magnetic field)
- At cryogenic temperature

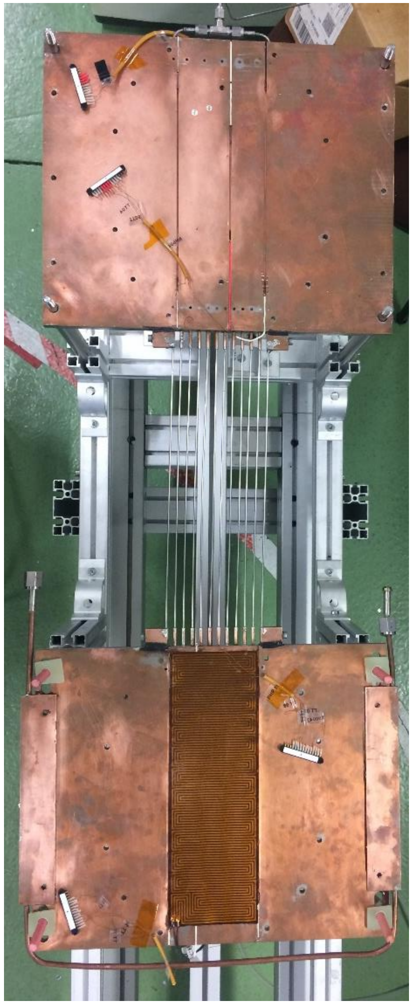
PHP DESIGN



Operating conditions	
Refrigerant	Nitrogen
Number of parallel tubes	36
Position	Horizontal
Inner diameter	1,5 mm
Condenser temperature	75 K

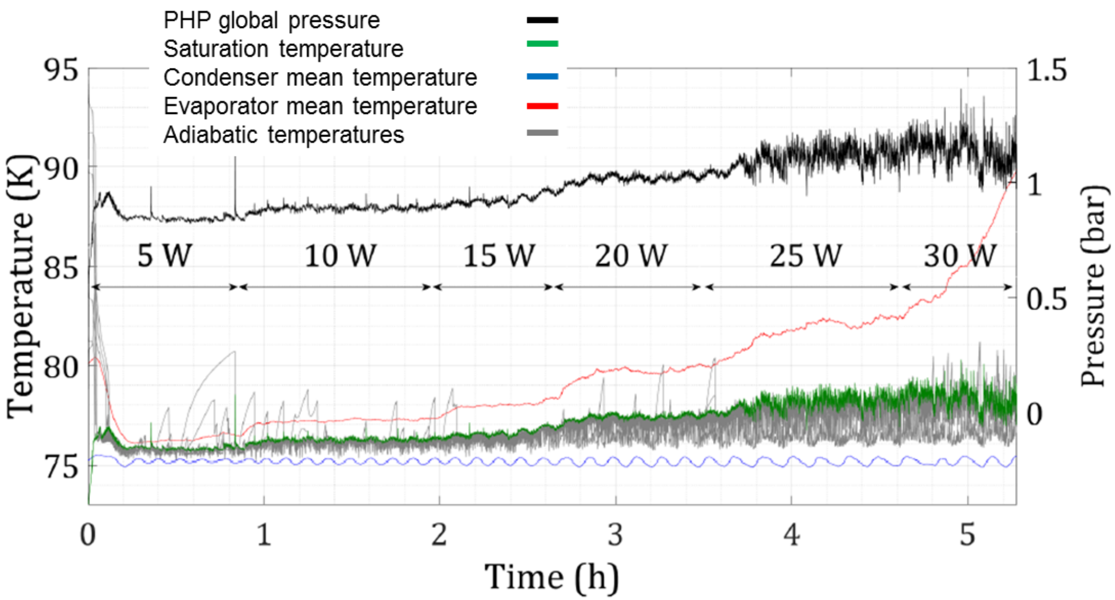
<table>
<tr><th colspan="3">Sensors</th></tr>
<tr><td rowspan="4">Temperature</td><td rowspan="3">Platinum (PT100)</td><td>6 Condenser</td></tr>
<tr><td>7 adiabatic part</td></tr>
<tr><td>5 evaporator</td></tr>
<tr><td>Cernox (1070 CX-SD)</td><td>1 evaporator</td></tr>
<tr><td rowspan="3">Pressure</td><td rowspan="2">Kulite</td><td>2 close condenser</td></tr>
<tr><td>2 close evaporator</td></tr>
<tr><td>MKS transductor</td><td>1 outside the cryostat</td></tr>
</table>

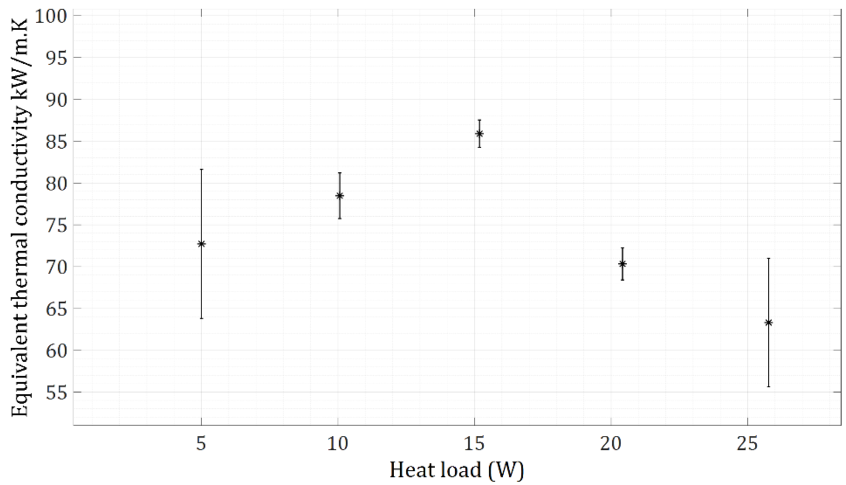

Condenser part with the inlet tube tin at the surface of the thermal link component
Cryocooler
Evaporator part with heaters taped at it surface to control the heat fluxes
Glass epoxy supports
Aluminum body sliding on the cryostat plate



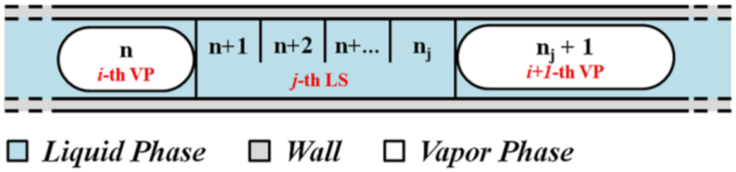
General Thermal Behavior

- 30 to 60 minutes to stabilize the temperature of the evaporator every time the heat load changes
- Maximum equivalent thermal conductivity of 85 kW/(m.K) at 15 W (42-45% real liquid fill ratio)
- Temperature of the evaporator highly increases between 15 and 20 W
- Pressure of the 4 sensors nearly the same (less than 0,2 bar difference) during the entire test
- Amplitude of pressure and temperature oscillations highly increases at 25 W
- At 30 W, the PHP can't perform the heat transfer

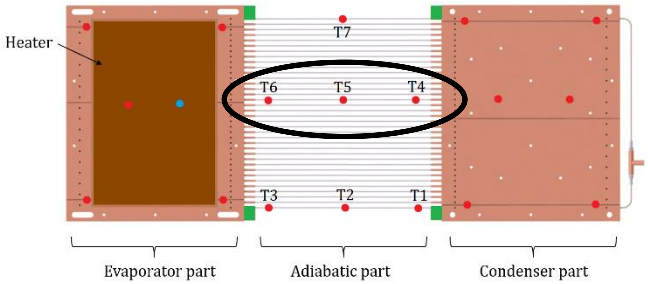




Numerical Model

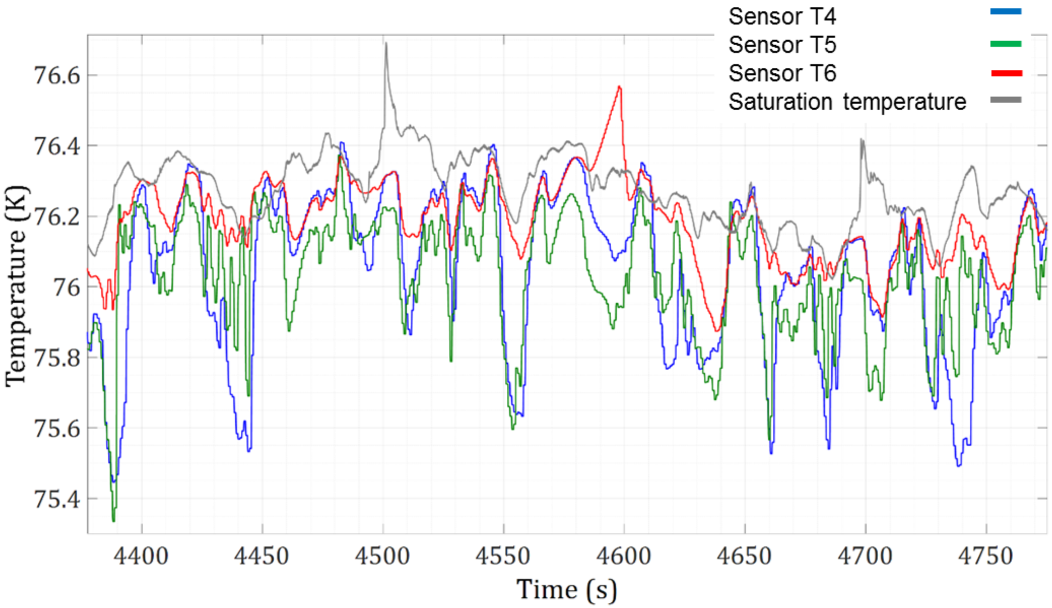


M. Mameli, Numerical model of a multi-turn Closed Loop Pulsating Heat Pipe, 2012



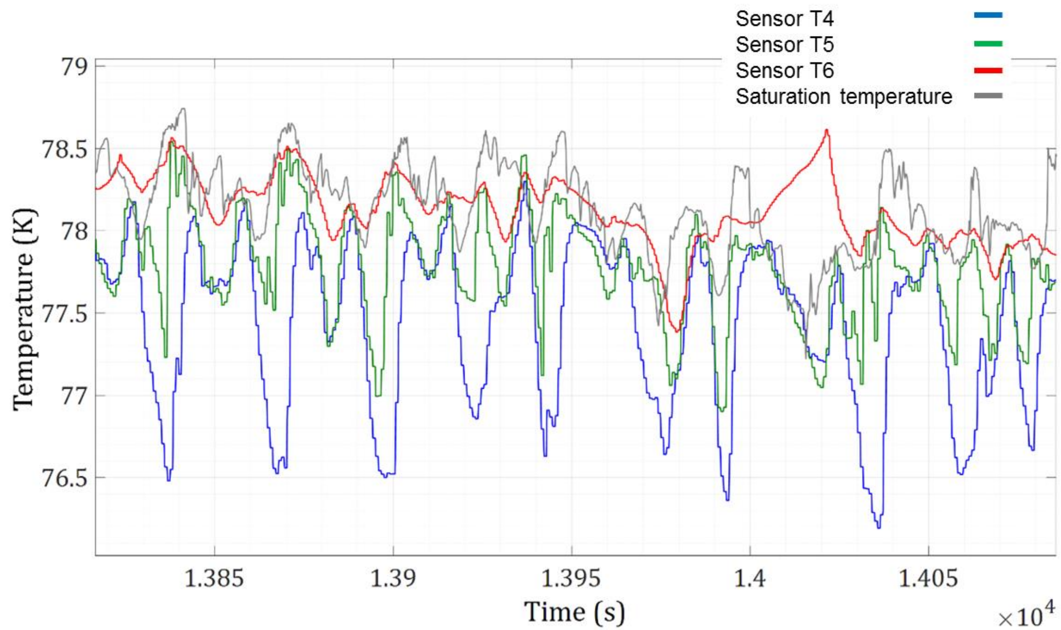
Low Heat Fluxes (5 and 10 W) :

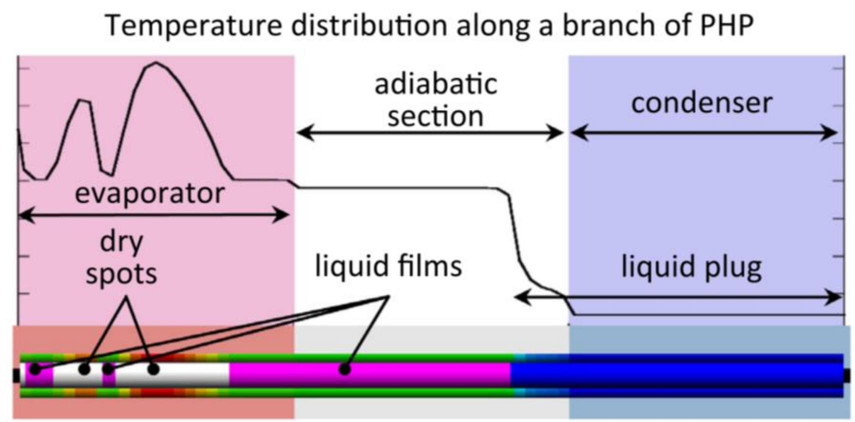
- Maximum temperature = Saturation temperature (related to the pressure)
- No Frequency
- Minimum temperature reached at sensor T4 or T5
- Temperature at sensor T6 very close to the Saturation conditions



High Heat Fluxes (15 and 25 W) :

- Frequency of 0,03 Hz visible in all sensors
- Amplitude of temperature oscillations of 0.3, 0.4 and 0.9 K at sensors T4, T5 and T6 respectively
- Uniform distribution of liquid slugs / vapor bubbles
- Local dry-out visible at T6 from 25 W



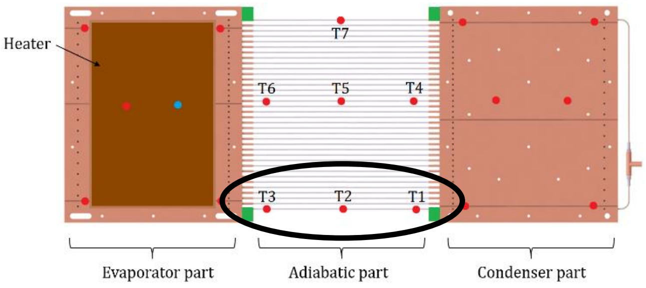


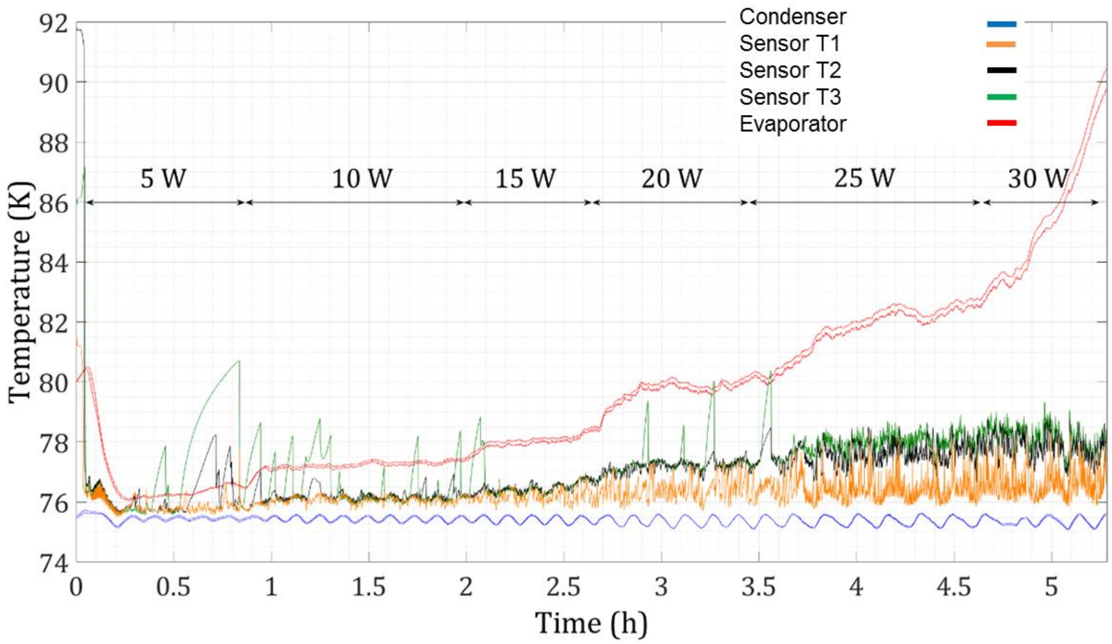
I. Nekrashevych, Effect of tube heat conduction on the pulsating heat pipe start-up, 2017

EXTERNAL TUBE

Tube in the adiabatic part close to the inlet of the PHP :

- Temperature peaks visible at T3 and T2
- Temperature sometimes higher than the evaporator at the beginning
- Mean temperature at T1 close to the condenser temperature (75 K)
- Local dry-out due to the large liquid slug

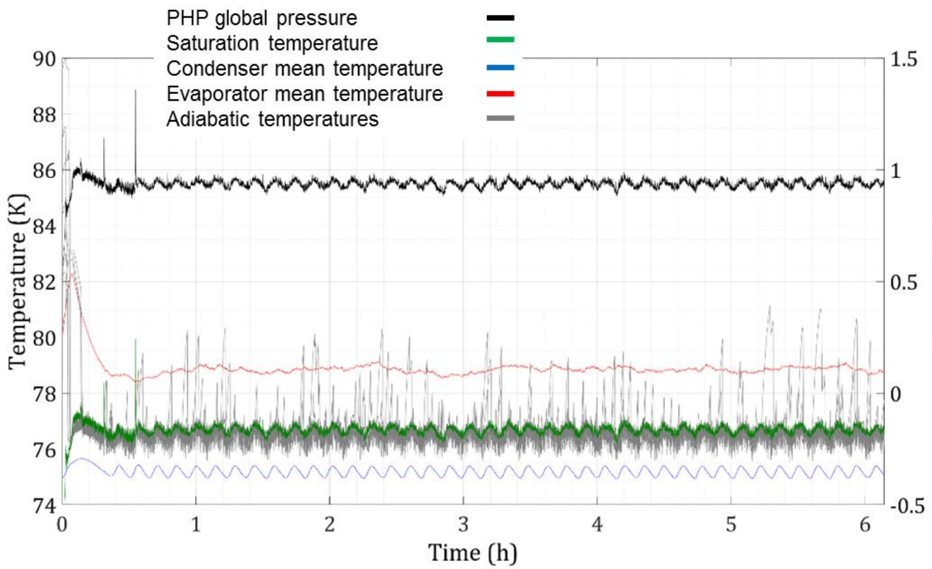




OTHERS EXPERIMENTS

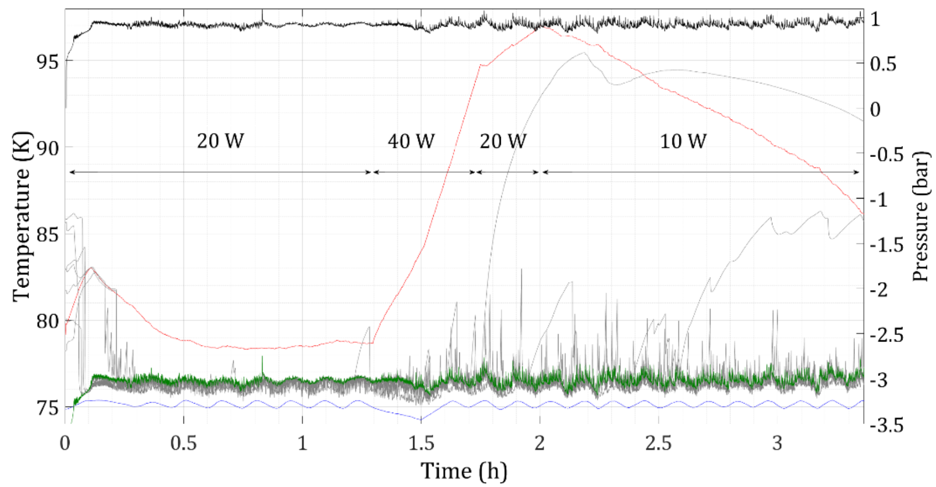
20 W (entire experiment) :

- 7 hours stable heat transfer
- Small real liquid fill ratio (about 35 %)
- Equivalent thermal conductivity of 88 kW/(m.K)



Up and down experiment :

- Imput power of 40 W after 1 hour of stability at 20 W
- No more heat transfer (condenser temperature decreases)
- High temperature and pressure oscillations
- Go back to 20 W after temperature reaches 95 K in the evaporator → temperature still increases
- With 10 W, Evaporator temperature decreases



CONCLUSION

Stable 1 m long Horizontal Pulsating Heat Pipe using N_2 :

- Max heat load of 25 W
- Max equivalent thermal conductivity of 85 kW/(m.K) at 15 W
- Two fluid distribution :
  - Low heat fluxes → Chaotic distribution
  - High heat fluxes → Uniform distribution (liquid slugs in the condenser and vapor bubbles in the evaporator)
- Stable during 7 hours (test stop because of the lack of security)
- After dry-out, with low heat fluxes, the PHP goes back to its regular thermal performance

Future :

- Test with neon around 25 K
- Test with 2 m long PHP (1,3 m long adiabatic part)