A Novel Pre-cooling System for Cryogenic Pulsating Heat Pipe

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Introduction

Among the different types of heat pipes, pulsating heat pipe (PHP) invented by Akachi in 1990 is a new-type heat pipe which has several outstanding features, such as great heat transport ability, strong adjustability, small in size and simple construction. PHP utilizes the pressure and temperature change in volume expansion and contraction during phase changes to excite the pulsation motion of liquid plugs and vapor bubbles in capillary tube between the evaporator and condenser.

For PHP at liquid helium temperature, the most important problem is the pre-cooling from room temperature to 4.2K. In conventional heat pipe, the pre-cooling is achieved by wick, which is infeasible in PHP. If the tube with poor thermal conductivity, less turns, thin thickness and long length, the cool down time is too long and cannot be unacceptable. We designed a mechanical-thermal switch worked as a pre-cooling system between the cryocooler and the evaporator, which was on during the pre-cooling process and off during the test process. By using the pre-cooling system, the cool down time of the cryogenic pulsating heat pipe was reduced significantly.

Conclusion

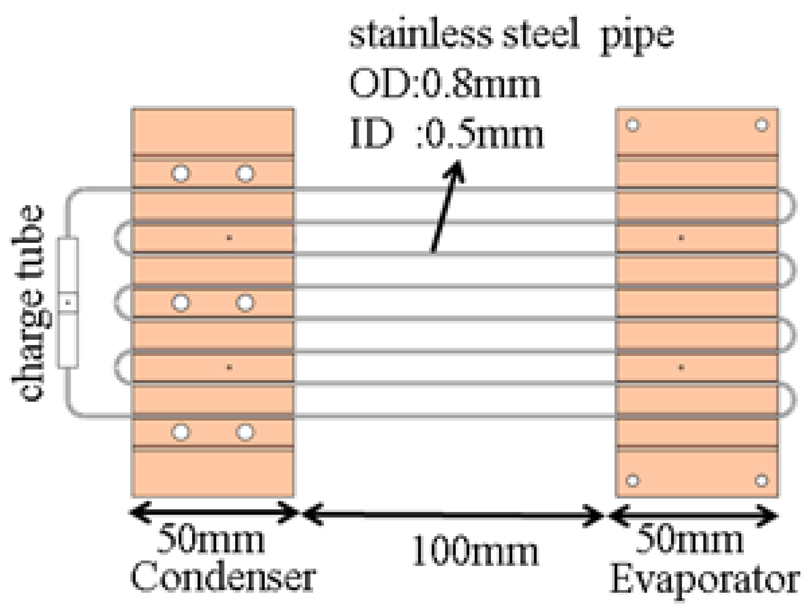
- A mechanical-thermal switch worked as a novel pre-cooling system for the helium PHP has been developed, which was on during the pre-cooling process and off during the test process.
- For the PHP set at horizontal orientation, the pre-cooling system reduced cooling time significantly and could cool down the PHP to operating temperature.
- For the PHP set at vertical orientation with the evaporator located at the bottom, the gravity played an important role and the pre-cooling system had no significant influence on the cooling time, which could not be used.
- The effective thermal conductivity of PHP set at vertical orientation was 13139.6 W/m·K (91.8mW).

PHP

Design of cryogenic PHP

$$D_{crit} \le 2\sqrt{\frac{\sigma}{g(\rho_l-\rho_v)}}$$ For helium, ≤ 0.6mm

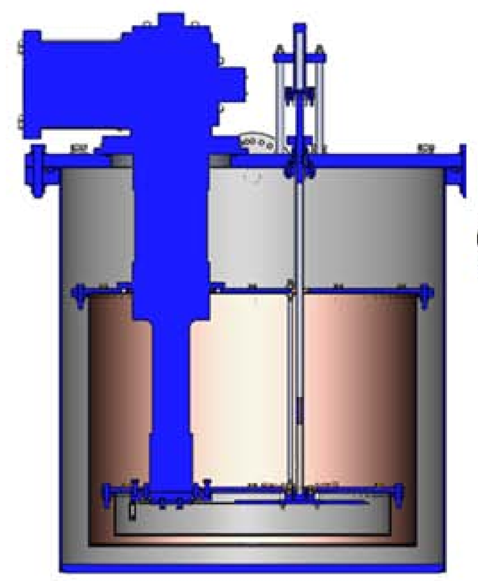
The stainless steel pipe of 0.8mm in outer diameter and 0.5mm in inner diameter was bent into 4 turns. The stainless steel was chosen because of low thermal conductivity, which could transport much smaller heat than PHP, and could distinguish the PHP worked or did not. The pipe was soldered onto two copper blocks, which were 4mm in thickness, 50mm in width and 120mm in length respectively. Therefore, the length of the evaporator section and condenser section were 50mm, and the length of the adiabatic section was 100mm. The copper block nearby the charge tube was connected to crycooler in order to eliminate the heat loss affection of inlet gas on measurement.

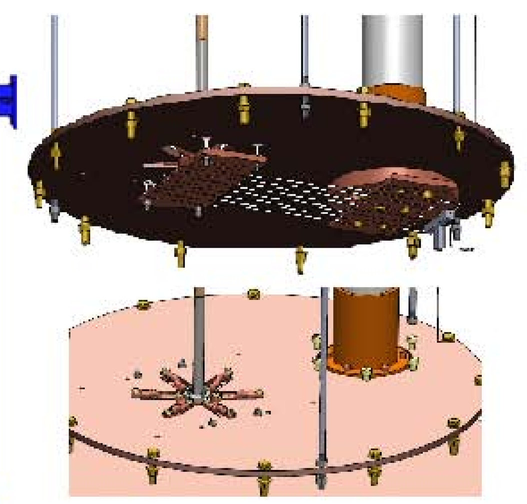


Pre-cooling system

Design of pre-cooling system

we designed a mechanical-thermal switch between the cryocooler and the evaporator worked as a pre-cooling system. The mechanical-thermal switch was thermally connected to the 4K thermal shield through copper braid. The copper block in the switch could be moved up and down to keeping thermal contact or not with the evaporator of PHP by spinning the end of switch rod at room temperature. Thus, the mechanical-thermal switch was on during the pre-cooling process and off during the test process.



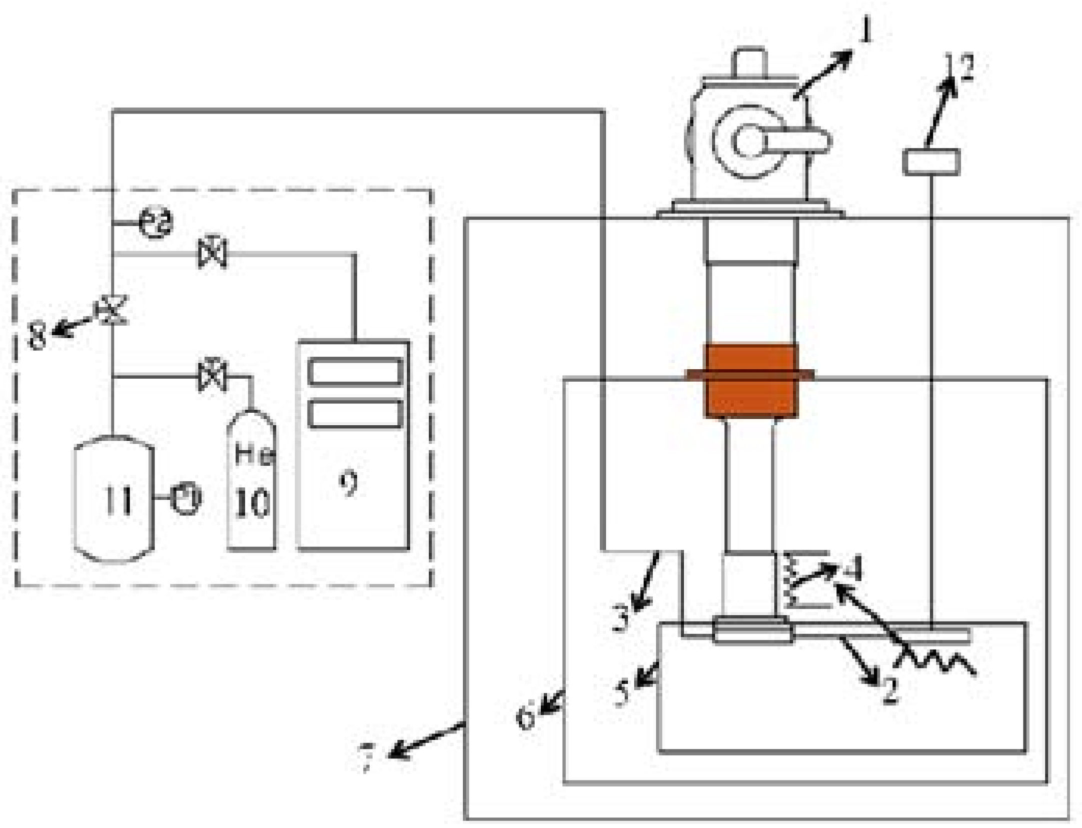


Experimental set-up

Design of Experimental set-up

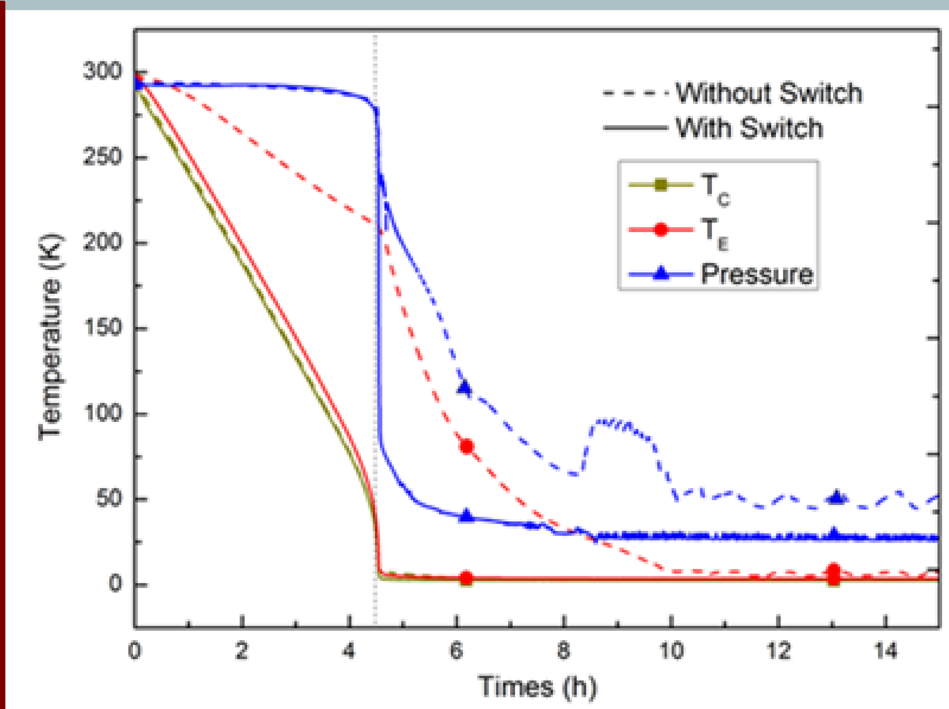
This experimental set-up could be used to test the PHP at different tilt angle. The PHP was set in a vacuum vessel and enclosed with first thermal shield and 4K thermal shield to reduce radiation heat. With the 4K thermal shield, the radiation heat transferred to PHP was negligible, and the heat power supplied by heater at evaporator section could be considered to be the heat transferred by PHP. If charge helium gas at room temperature with liquid filling ratio 100%, the pressure in PHP is 78MPa, which is obviously unreasonable. Therefore, the charge tube was connected to a buffer tank to charge the helium gas along with the cooling process. A vacuum pump and gas cylinder were used to purify the PHP system through two valves and the number of replacement with 99.999% helium gas should be more than 10 times.

One of the pressure gauges was placed in the charge tube to monitor the pressure change of PHP and another was placed in the buffer tank to control the liquid filling ratio (LFR).

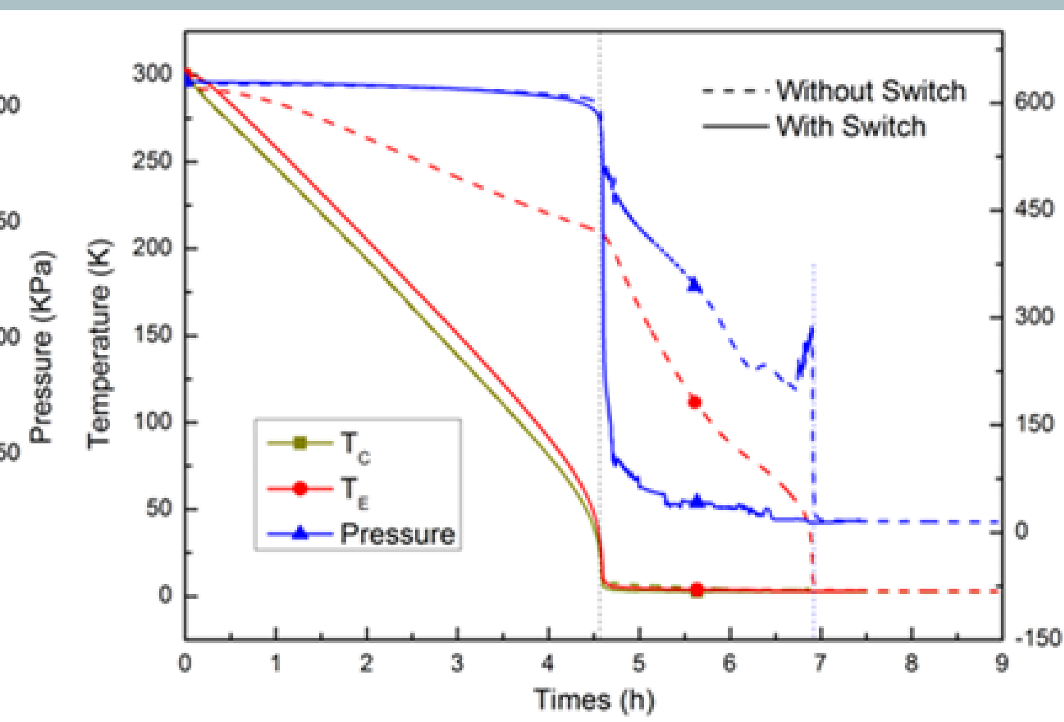


1: G-M cryocooler; 2: pre-cooling system; 3: charge tube; 4: heater; 5: 4K thermal shield; 6: first thermal shield; 7: vacuum vessel; 8: valve; 9: vacuum pump; 10: gas cylinder; 11: buffer tank;

Results and discussion



PHP at horizontal orientation



PHP at vertical with the evaporator located at the bottom

Vertically:

the initial temperature different ΔT1 of evaporator and condenser was 0.245K.

When 91.8mW was supplied, the temperature of evaporator increased and reached to 4.89K.

The effective thermal conductivity was 13139.6 W/m·K.

Horizontal: With the switch, the temperature of evaporator dropped rapidly with the temperature decreasing of condenser. It took 4.5hrs for evaporator to be cooled down to 7K and 8hrs to a steady state (the temperature of condenser is 2.7K and the temperature of evaporator is 3.7K). However, without the switch, the temperature of evaporator dropped slowly. It took 12hrs for evaporator to a steady state, when the temperature of condenser was 2.7K and the temperature of evaporator oscillated between 5K and 7K.

Vertically: With the switch, it took 6hrs to a steady state (the temperature of condenser was 2.7K and the temperature of evaporator was 3.2K). However, without the pre-cooling system, it took 6.8hrs for evaporator to 50K, and then the temperature of evaporator dropped rapidly to 3K within an hour. It meant that there was liquid helium reached to evaporator from condenser.