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CLOSED LOOP PULSATING HEAT PIPE: GROUND AND MICROGRAVITY EXPERIMENTS

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1 INTRODUCTION

The Pulsating Heat Pipe (PHP) is a thermally driven two-phase passive device mainly based on the interplay between phase change phenomena (film evaporation, flow boiling, film condensation) and capillary forces. Because of its low cost and its potential capability to operate without gravity, it is one of the most novel, promising devices for the thermal control of electronic equipment for ground and space applications [1,2]. Thanks to the capillary dimension of the internal diameter (usually between 1 and 2mm) gravity is not essential to the PHP operation but affects its thermal performances. This paper presents both ground test data and the results obtained during the 59th parabolic flight campaign organized by ESA in October 2013, complementary to those collected during the 58th parabolic flight campaign performed in May 2013 [3,4]. In particular the same Closed Loop PHP, made of a copper tube (I.D. 1.1mm, O.D. 2mm), bent into 16 turns and filled with FC-72, has been tested with a different volumetric filling ratio: 70%, while in the previous campaign the PHP has been filled 50%. The device is investigated in the vertical bottom heated configuration and results confirm that, during a parabolic flight, the PHP operation is strongly affected by the gravity field variation: hyper-gravity (1.8g) slightly assists the flow motion while during microgravity the PHP undergoes sudden temperature increases in the evaporator zone. The second hyper-gravity period is able to bring the PHP back to the previous thermal regime.

2 EXPERIMENTAL FACILITY

Figure 1 shows the main dimensions of the PHP with only the heater and thermocouples. The present PHP is equipped with a wire electrical heater (Thermocoax® Single core 1Nc Ac) wrapped 20 times around each evaporator U-turn in order to cover an evaporator length of about 6 mm and connected to a power supply (GWInstek® 3610A). Thermal characterization is provided by means of twelve "T" type thermocouples (wire diameter 0.127mm) located both in the evaporator and condenser zone (Figure 1). Furthermore the local fluid pressure fluctuations are recorded by means of a pressure transducer (Kulite®, ETL/T 312, 1.2bar A) plugged in the condenser section. The PHP is evacuated by means of a ultra-high vacuum system (Varian® DS42 and TV81-T), filled with degassed FC-72 (FR=70%) and finally sealed. The condenser section is embedded into an aluminum heat sink (Figure 2) which is cooled by means of four air fans. The CLPHP test cell as well as the cooling fan system are mounted on a tilting structure in order to test it at different inclination angles. Thermocouples and the pressure transducer are connected to a data acquisition system. (NI-CRio) and signals are recorded at 16Hz.

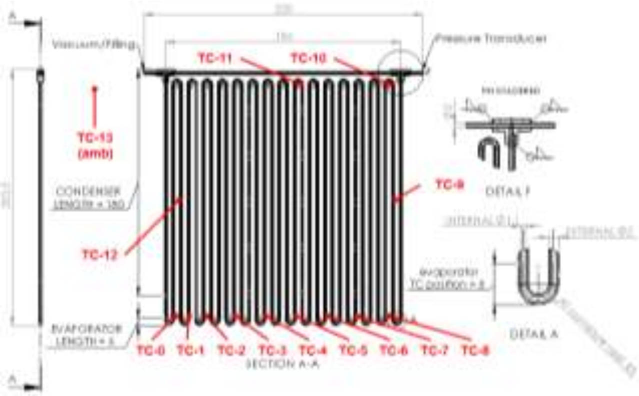

Figure 1: CLPHP test cell geometrical dimensions.

Figure 2: heat sink embedded PHP with pressure sensor and thermocouples.

3 RESULTS

Results are presented mainly in terms of temperature and pressure time evolutions. The tube wall temperature trends, both in the evaporator zone (reddish colors), condenser zone (bluish colors), and environment (green), are shown together with the heat input level on the secondary y-axis. Separately the local fluid pressure in the condenser together with the heat input level on the secondary y-axis. In case of flight test, the gravity acceleration is reported directly over the plot line.

3.1 Ground Tests

The complete thermal characterization in vertical and horizontal position has been performed ranging from 10W to 100W heating power with steps of 10W. Each step is kept for at least twenty minutes in order to reach the pseudo-steady state (all temperature signals shows an average component which is time constant). Figure 3 shows the PHP thermal behavior during the Vertical operation.

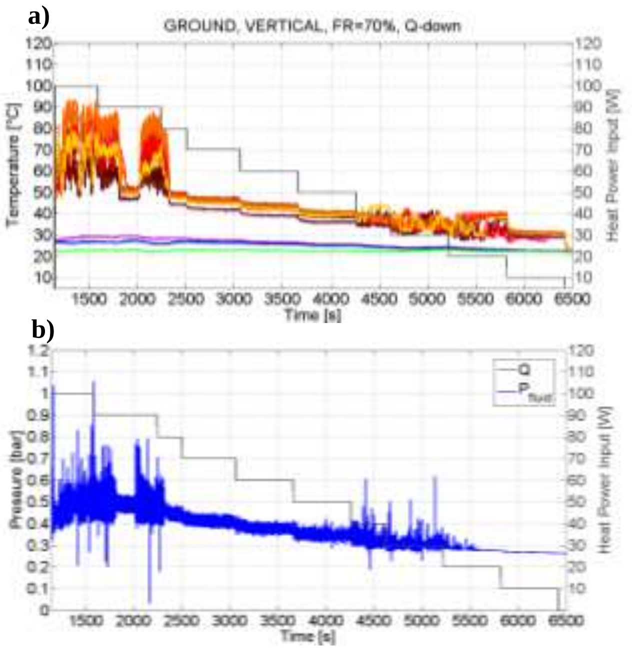

Figure 3: Vertical PHP on ground with different thermal loads: a) wall temperatures, b) local fluid pressure in the condenser.

Besides being more stable and efficient than the horizontal operation, the vertical PHP shows an interesting feature at high heat input levels (80W to 100W): some channels undergo a sudden thermal instability probably due to fluid motion dampening or local dry-out [5]. During this crisis the temperature distribution spreads op to 40°C while when the device works in a stable condition (from 80W to 50W) the evaporator temperature range is always narrower (less than 10°C). Between 40W and 20W the device undergoes a start-stop condition and does not operate at all at 10W.

3.2 Parabolic Flight Campaign

The same PHP is then tested during the 59th ESA Parabolic Flight (PF) campaign with a variable gravity regime (from 1.8 down to 10^{-2} g, 31 parables). As shown in figure 4, during a parabolic flight maneuver (1g, 1.8g, 0g, 1.8g, 1g), the vertical operation is affected by the gravity field variation as follows:

- hyper-gravity assists the flow motion, the heat transfer is slightly enhanced, thus a small decrease of the evaporator temperatures is appreciable.
- during microgravity the gravity force component is not present anymore and the PHP undergoes sudden temperature increase in the evaporator zone.
- during the microgravity period the pressure fluctuations are higher in amplitude but occur with lower frequency (Fig. 4b) similarly to the horizontal position on ground.
- the second hyper-gravity period is able to bring the PHP back to the previous thermal regime.

4 CONCLUSIONS

A Closed Loop Pulsating Heat Pipe filled with FC-72, has been investigated both on ground and in micro/hypergravity conditions during the 59th ESA campaign with 70% volumetric filling ratio. Ground tests are performed on ground at different heat input levels, and different orientations (Vertical, Horizontal). Results confirmed that despite the capillary inner diameter, the PHP thermal-hydraulic behavior is strongly affected by the orientation and by the gravity level. In particular:

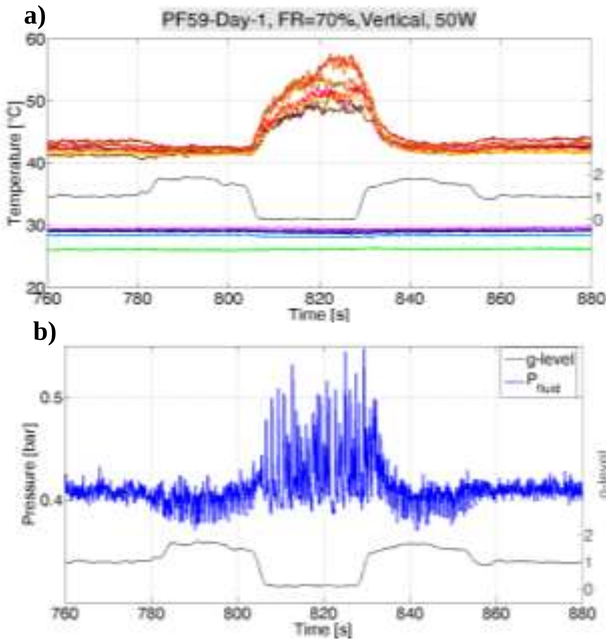

Figure 4: Vertical PHP during a parabolic maneuver: a) wall temperatures, b) local fluid pressure in the condenser.

- the vertical operation is more stable and efficient while the horizontal mode is characterized by an impulse driven flow with apparently lower oscillation frequency.
- a repeatable thermal instability is detected at high heat input levels for the vertical operation due to partial dry-outs.
- In case of perfectly planar geometry the horizontal operation on ground seems to be the most similar to the micro-gravity operation.

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REFERENCES

1. Akachi H., Structure of a heat pipe. *US Patent 4,921,041*. (1990).
2. Maydanik Y., Dmitrin V.I.,. Pastukhov V.G, Compact cooler for electronics on the basis of a pulsating heat pipe. Applied Thermal Engineering, vol. 29, 3511–3517 (2009).
3. Araneo L., Filippeschi S., Mameli M., Marelli L., Testa R., Manno V., Marengo M. Thermo-Hydraulics Characterization Of A Pulsating Heat Pipe in a Variable Gravity Regime 8th International Topical Team Workshop on Two-Phase Systems For Ground And Space Applications. Bremen, Germany, September 16-19, 2013.
4. Mameli M., Araneo L., Filippeschi S., Marelli L., Testa R., Marengo M., Thermal Response of a Closed Loop Pulsating Heat Pipe under Varying Gravity Field, accepted for publication on the Int. J. of Thermal Sciences, DOI: 10.1016/j.ijthermalsci.2014.01.023.
5. Mameli M., Manno V., Filippeschi S., M. Marengo, 2013, Effect of Gravity on the Thermal Instability Of a Closed Loop Pulsating Heat Pipe, 8th World Conference on Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics June 16-20, 2013, Lisbon, Portugal.