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Standardization of Thermal Interface for Future Space Missions

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Abstract

This paper presents the thermal IF of SIROM project that has been developed by MAG SOAR. SIROM project, funded by the European Union´s Horizon 2020 research and innovation programme, aims to advance on the key-points of Space Robotics Technologies. This multi-functional standard interface provides mechanical, power, data and thermal connectivity on a limited space (diameter 120mm and height of 30mm).

This high-power transmission is achieved using a Close-Loop Fluid Heat Exchange Module (CL-FHEM). Test were divided at component level in order to characterize the coupling force at different temperature range (-40ºC up to 70ºC) and at integrated systems level where different values such as heat transfer, pressure drop and leakage were obtained. Due to the industry interest of the technology, an optimized version of the proposed thermal IF has been founded by Horizon 2020 in the context of MOSAR project [1].

1. Introduction

The vision of SIROM for the future is to provide a European capability able to achieve cost savings and higher operational flexibility for spacecraft orbital missions. To motivate the productivity of the satellite industry, secure safety of satellites in orbit and planetary operations and to improve the ecological effects of space activities [2].

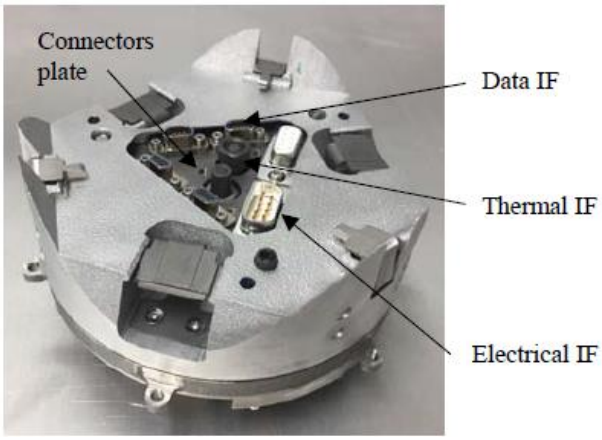

Figure 1: SIROM functional interfaces- SENER© [2]

The objective of the project is to study innovative concepts of a standard IF for mechanical connection, transfer of power, data and heat load between Active Payload modules (APM) ´s which could support European space companies for their space robotics servicing capabilities.

The paper is structured in three main sections. Initially, the schematic representation of the hydraulic system is presented, experimental set up and the manufactured thermal IF. Secondly, the experimental results are presented and discussed. Finally, the main conclusions of the thermal IF are summarized.

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2. Experimental set up

SIROM thermal IF consist in two hydraulic connectors (one male and one female) integrated in a structural part (see figure 1 and 2). Two flexible metallic bellows are used to accommodate the required stroke for connection of the whole SIROM IF. Additionally, two redundant NTC temperature sensors are integrated in the SIROM thermal IF in order to measure the temperature before connection. In the figure bellow, it is presented the manufactured SIROM thermal IF and a diagram of the fluid circuit through it.

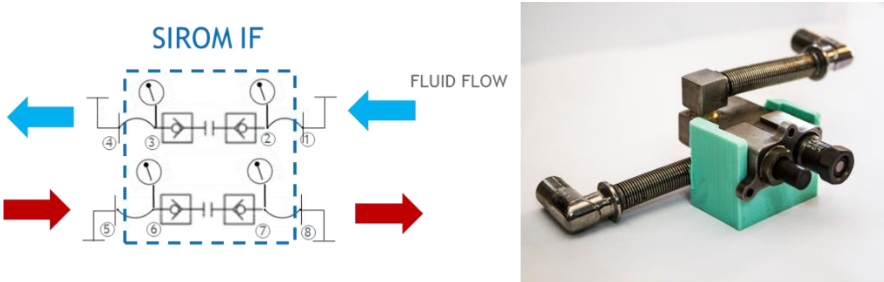

Figure 2: Thermal IF SIROM

Tests are based on a Close-Loop Fluid Heat Exchange Module (CL-FHEM) composed of two block modules of size 200x150x160mm. In the figure below is depicted the schematic representation of the CL-FHEM.

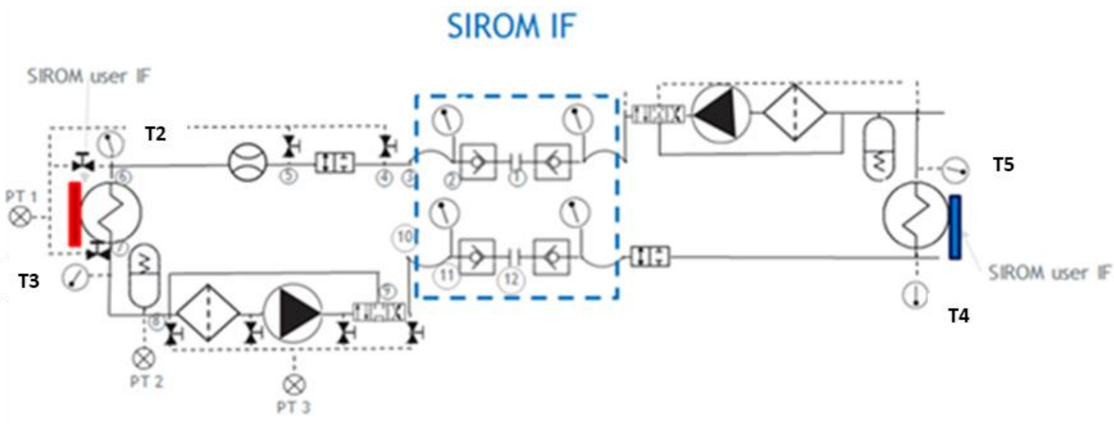

Figure 3: Schematic representation of the CL-FHEM

As depicted in the following figure, each circuit includes the following components:

- A micropump with a maximum flow of 2.2 l/min
- Selective filter to prevent damage to the pump
- Three electro valves
- Accumulator to absorb the fluid thermal expansion.

In addition, pressure and temperature sensors along the circuits are placed outside the envelope of the CL-FHEM in order to characterize pressure and temperatures along the circuit. Test were performed at ambient pressure and water was included as a fluid (Cp=4180 J/kgK, ρ=1000 kg/m3 reference values).

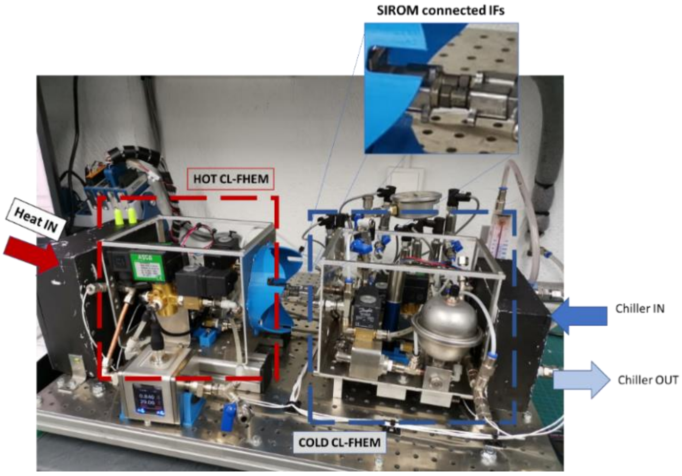

Figure 4: Breadboard models high power Thermal IF

3. Experimental results

Initially, the pressure drop of the SIROM interface has been characterized. Tests are performed at room temperature; no heater nor chiller is connected. Static pressure on the CL-FHEM modules is 3.5 bar at ambient pressure with no equipment connected. The nomenclature for each point in the hydraulic line have been defined based on Fig. 3. The total pressure drop of the hydraulic circuit has been calculated as superposition of the different pressure drops along the circuit path. It is observed an experimental drop of 3.62 bar in the line. As depicted on Table 1, these results are in accordance with the theoretical pressure drop estimated.

Table 1: Pressure drop in the different parts of the circuit

Section of CL-FHEM	Theoretical pressure drop		Experimental Drop [bar]
	Primary Drop [bar]	Secondary Drop [bar]	
1-4	8,95E-02	0,303	0,293±0,042
4-5	0,0E+00	0,248	0,738±0,042
5-6	1,6E-02	0,057	0,236±0,042
6-7	7,4E-01	0,000	0,843±0,042
7-8	5,4E-03	0,007	0,017±0,042
8-9	0,0E+00	0,800	1,190±0,042
9-12	8,95E-02	0,571	0,299±0,042
Total Pressure Drop (2 active pumps)	**2,63 bar (each)**		**2,42±0,042 bar (each)**
Total Pressure Drop (1 active pump)	**4,30 bar**		**3,62 ± 0,29 bar**

In order to better understand the thermal profiles of the tests, the figure below presents the typical temperature profile during the high-power thermal IF. T3 and T2 are the output and input temperature of the hot exchanger respectively. On the other hand, T4 is the input temperature to the cold heat exchanger and T5 is the output temperature of the cold heat exchange in the CL-FHEM module as shown in Fig. 3.

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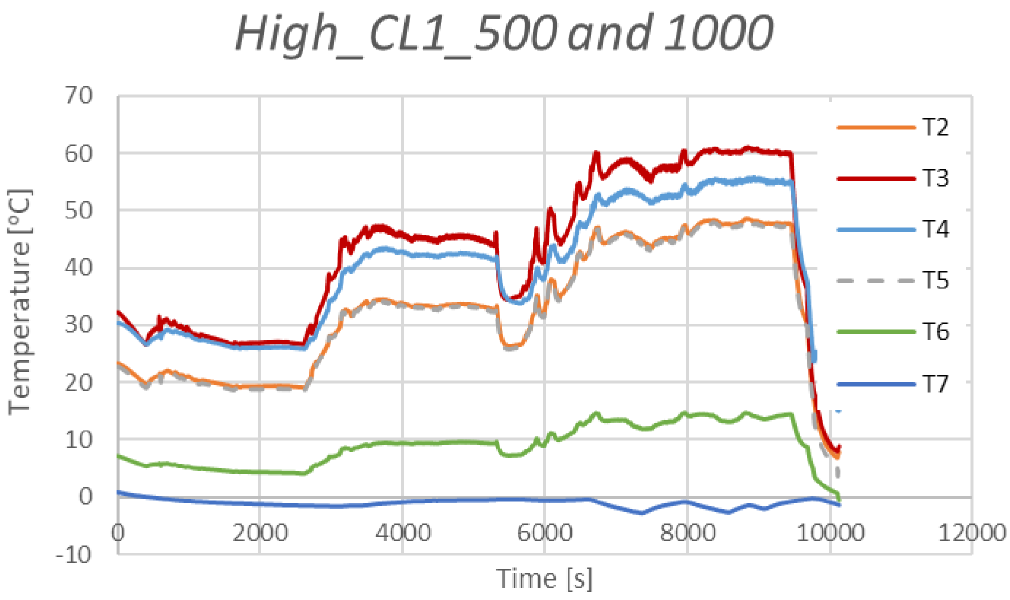

Figure 5: Temperature profile during 500 and 1000 W tests.

For the calculation of the heat exchange in the hot IF of SIROM, the following equation is considered:

$$\dot{Q}_{HOT\_IF} = V \cdot \rho \cdot C_p \cdot (T_3 - T_2) \quad (1)$$

The sign of the heat exchanged in the cold IF power is forced to be positive by sign convention. Therefore, it is calculated as:

$$-\dot{Q}_{cold\_IF} = V \cdot \rho \cdot C_p \cdot (T_4 - T_5) \quad (2)$$

Finally, an independent water refrigeration circuit (chiller) is used to evaluate the heat from the SIROM thermal breadboard. It takes the heat exchanged in the cold IF an evacuates it to the environment. Despite is not a value required in the project, the heat exchanged in the chiller is:

$$\dot{Q}_{chiller\_IF} = V_{chiller} \cdot \rho_{chiller} \cdot C_{p_{chiller}} \cdot (T_6 - T_7) \quad (3)$$

In the figure below it is observed the characteristic heat curves of the overall system. It is observed a quasi-stationary tendency of the critical heat sources.

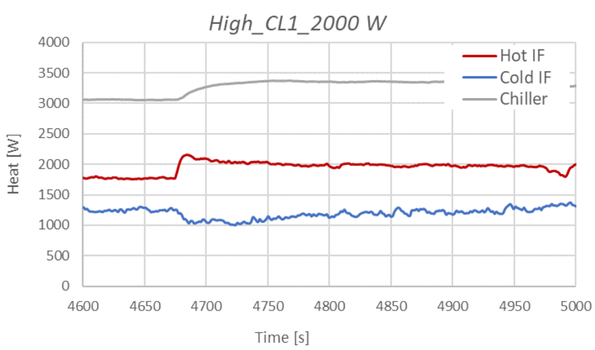

Figure 6: 2000 W test results

To visually understand the experimental temperature maps of the system, infrared pictured were taken during the test campaign (see figure below). Based on the know-how of MAG SOAR, this set up will be optimized during MOSAR project [1].

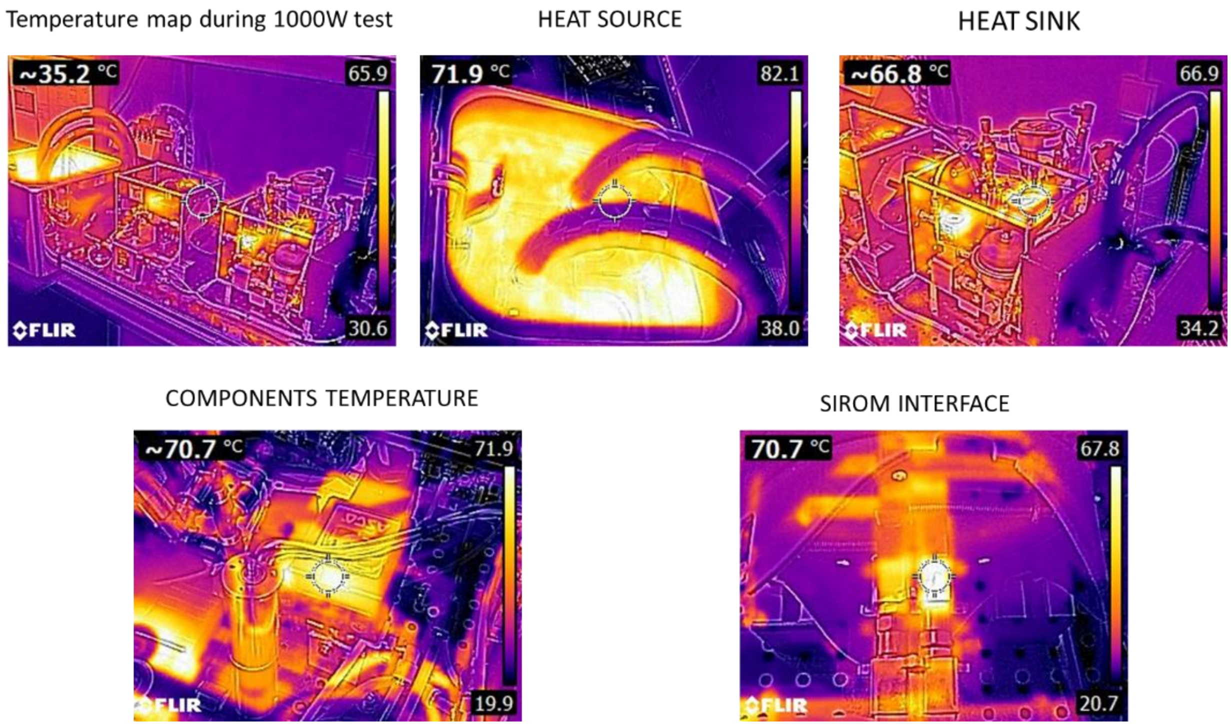

Figure 7: Infrared pictures during the experiments

The efficiency of the thermal exchange between the hot IF and the cold IF of the CL-FHEMs is calculated as:

$$\boldsymbol{Eff} = \left|\frac{\dot{\boldsymbol{Q}}\boldsymbol{cold}}{\dot{\boldsymbol{Q}}\boldsymbol{hot}}\right| \tag{4}$$

In the figure below, the efficiency of the breadboard model is presented against the hot IF heat exchange. An average efficiency of 55% is measured between 250 and 2200 W. It is clear that there is plenty of room for improvement and as a primary objective MOSAR will aim to increase the presented efficiency.

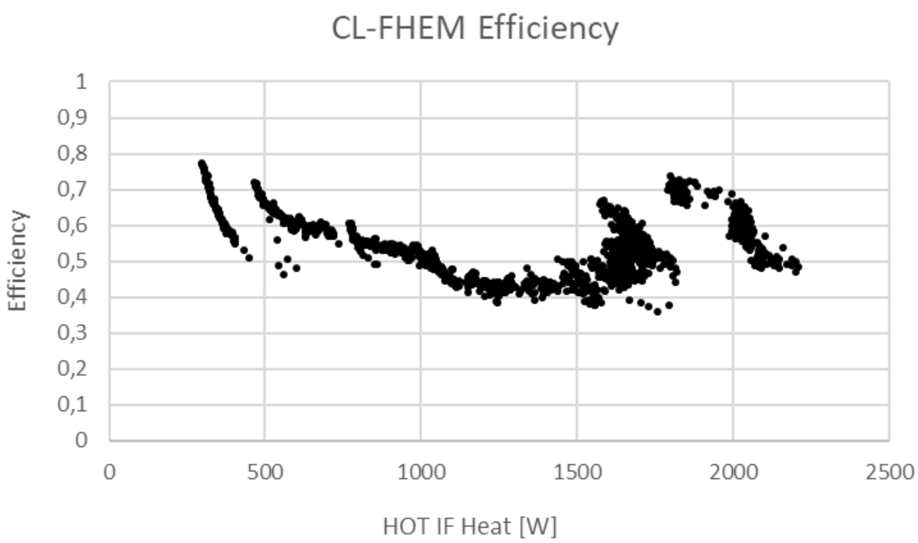

Figure 8: Efficiency of the heat exchange between CL-FHEM hot and cold IFs.

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4. Conclusions

A thermal interface between connecting space APM has been developed by MAG SOAR. The IF is based in a double-quick connecting system for fluid circulation and heat exchange between a heat source and a heat sink up to 1400W (cold side). The operational temperature of the thermal IF is ranged between -40 to 100 °C.

A maximum connecting force of 67.2±0.5 N has been measured with low dependency of the environmental temperature. In addition, for connection and disconnection of the SIROM IF no leakage is observed provided the pressure in the line is that of the environment. Due to the industry interest of the technology, an optimized version of the proposed thermal IF has been funded by Horizon 2020 in the context of MOSAR project [1].

References

[1] https://cordis.europa.eu/project/rcn/218710/factsheet/es

[2] J. Vinals et al, 2018, FUTURE SPACE MISSIONS WITH RECONFIGURABLE MODULAR PAYLOAD MODULES AND STANDARD INTERFACE- AN OVERVIEW OF THE SIROM PROJECT