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THERMAL CONDUCTANCE EXPERIMENTAL DETERMINATION IN SIMULATED DEEP SPACE ENVIRONMENT

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Abstract: *Thermal conductance measurement in the simulated deep space and Martian atmosphere conditions is one of the key objectives in the Miniaturized Heat Switch redesign and development project. The experiments are to be performed in the thermo-vacuum test chamber, once the measurement interference and accuracy are determined. For this purpose, calibration specimens were manufactured and tested. The tests were performed under* 10^{-3} *Pa pressure, according to the qualification requirements. The data were used to design test apparatus´s thermal model, capable of specimens thermal conductance evaluation. The thermal model results identified potential refinement parameters. The model applicability should be verified once a sufficient amount of data is evaluated.*

Keywords: Thermal conductance, Space environment, Testing.

1. Introduction

Space: the final frontier. These have been the voyages of the humankind since Sputnik 1 was launched in 1957. The ability to provide space technology on ground testing is a mandatory part of the development process, present in every space project. The Institute of Aerospace Engineering (IAE) has participated in the European Space Agency (ESA) tender aiming at a Miniaturized Heat Switch (MHS) prototype development since 2015 (Mašek et al., 2017). The Institute is responsible for the environmental and mechanical testing of the device, capable of autonomous and powerless temperature regulation.

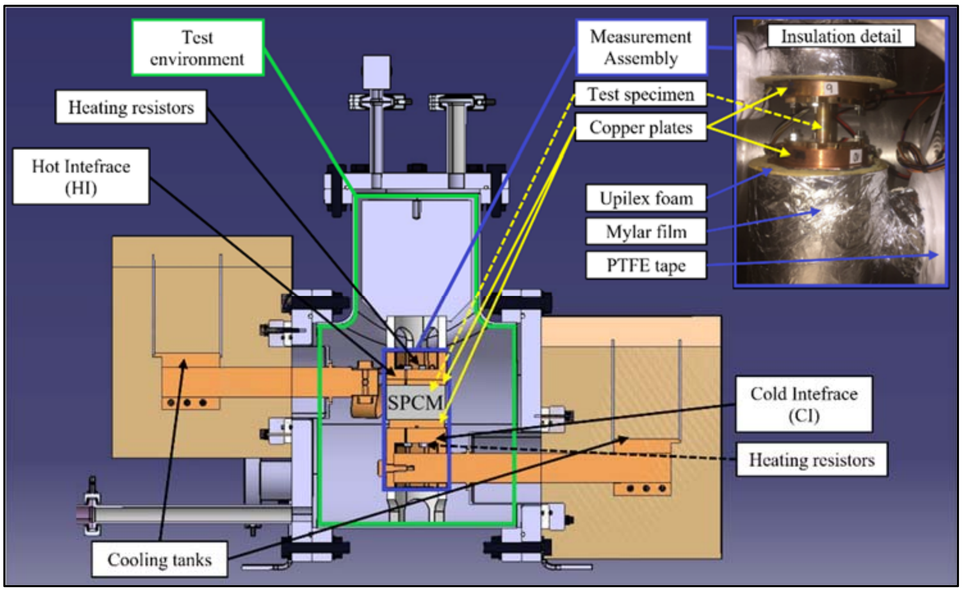

Fig. 1: Test apparatus cross-section, inner specimen position and insulation detail.

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The test apparatus was built at the Institute to be able to measure the MHS´s thermal conductance in a specified condition. A complex Thermal Model (TM) was created based on the calibration measurements, to determine the specimen´s thermal conductance and therefore to validate the parameters used in the model. The model relies on the heat loses calculation in specified simulated conditions. The principle was described in detail by Lazar (2019). This paper is reviews progress in the test facility calibration, specimen design, and TM evaluation method.

2. Miniaturized Heat Switch and test specimens

The specimens with MHS representative parameters were designed for the thermo-vacuum calibration task experiments. On and off Heat Switch modes were covered by the V3 Open and V3 Closed specimens, MHS transition range (on to off) by the V3 Mean specimen. The specimen´s parameters are in Tab. 1.

Tab. 1: MHS & V3 specimens parameters.

MHS		V3 specimens	
Mode	T. conductance [W/K]	Type	T. conductance [W/K]
ON	1	V3 Closed	1.008
OFF	0.01	V3 Open	0.016
		V3 Mean	0.200

Bronze (CuSn8) was found suitable for the Mean and Closed design for its thermal conductivity. Thermal conductance of the particular specimens was modified by the central section thickness (Fig. 2d). Polytetrafluoroethylene (PTFE) was chosen for the Open specimen, for the thermal-insulation requirements.

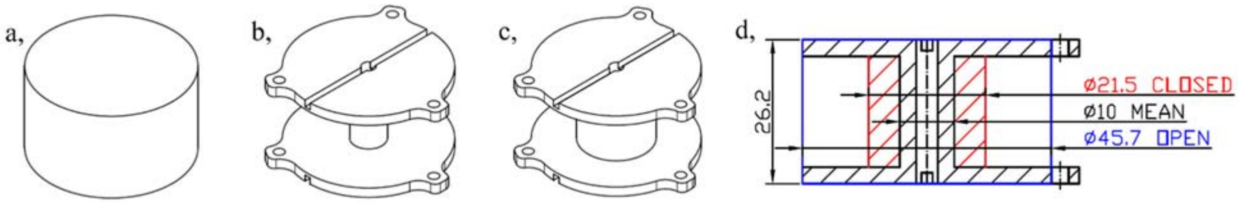

Fig. 2: a, V3 Open; b, V3 Mean; c, V3 Closed; d, dimensions comparison.

3. Experiment the Thermal Model evaluation

The V3 specimens were subjected to a total of 15 measurements. The goal was to calibrate and validate the measurement evaluation process and its accuracy. Particular measurement settings are the combination of input Hot Interface Heat Load (Q_{in}), Constant temperature (TC_{2-7}) and the specimen type.

Tab. 2: Experiment´s conditions.

Parameter	Experiment state
Pressure	$1.3\cdot10^{-3} \div 3\cdot10^{-3}$ [Pa]
Gas	Air
Q_{in} Heat Load	2, 4, 7 [W]
TC_{2-7}	-15, 0, 15 [°C]
Specimen	V3 Closed, Mean, Open

Specimens were placed in between the Hot (upper) and Cold (lower) Copper Plate (CP). Temperature probes (TH_{2-7}, TC_{2-7}) were mounted on the specimen´s side of a CPs. The constant temperature (TC_{2-7}) was maintained on the Cold CP with a temperature regulation system including a temperature controller, heating resistors and cooling tanks (for liquid nitrogen cooling). Only steady state temperatures, defining the stationary task for evaluation, were used (see Figs. 1 and 3 for measurement assembly composition).

Upilex foam and Mylar film covered the measurement assembly (including specimen and CPs) during the experiments. The remaining parts were insulated with PTFE tape (see Fig. 1 for the insulation details). The insulation was applied so that the heat exchange between the measurement assembly and inner facility environment could be reduced.

4. Thermal Model

A Thermal Model was designed as a mathematical interpretation of the inner test facility processes. The model combines input parameters and measured temperature values in a pre-defined set of equations. Heat losses caused by thermal radiation and thermal convection were determined for each part of the measurement assembly (HI, CPs, Specimen, CI). The output parameters were: thermal conductance, Thermal Contact Resistance (TCR), radiation heat loss (R_X) and convection heat loss (K_X). The final thermal conductance of the specimen was determined from equation (1):

$$C = \frac{Q_{out3}}{\Delta T_2} \tag{1}$$

The Q_{out3} is the original Hot Interface Heat Load, lowered by the radiation (R1, R2) and convection (K2, K2) heat losses. Temperature difference ΔT_2 between the Hot and the Cold CP was determined based on the measured temperatures TH_{2-7} and TC_{2-7} (see Fig. 3 for details).

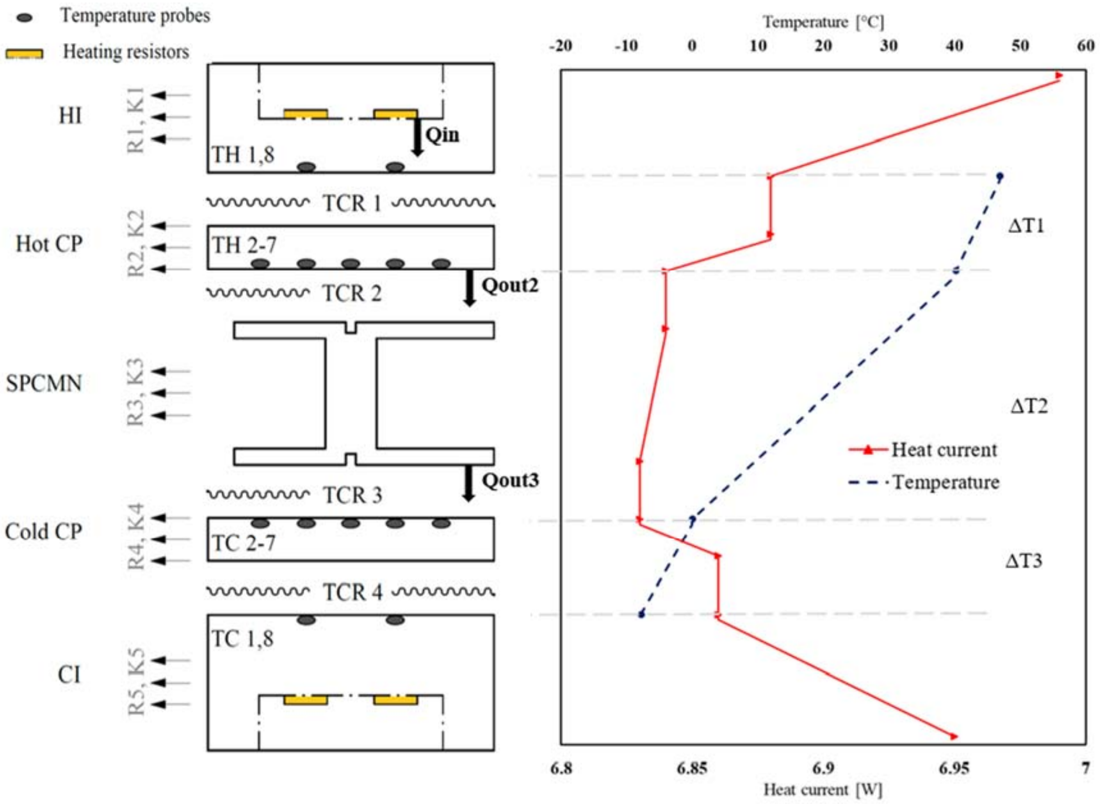

Fig. 3: Measurement assembly (left) and temperature & power distribution within the assembly (right) during the V3 Closed calibration experiment.

The most significant temperature drop was caused by Thermal Contact Resistance (TCR) in between the assembly parts (layers). TCR and its effect was described by Gilmore (2003). TCR measurement and prediction methods were studied by Mateášik (2019). The TCR predictability is a key for the future Thermal Model simulations and MHS performance optimization. However, existing TCR models are not suitable for our specific application due to uncertain material and geometrical properties of the specimens.

In the TM calculations, the TCR was cleared from its physical properties dependences. Similarly to thermal conductance (1), the steady state temperature difference and modified input power were used. TCR was assumed as:

$$TCR_2 = \frac{\left(\frac{(TH_{2-7} - TC_{2-7})}{Q_{out2}} - R_{SPCM}\right)}{2} = TCR_3 \tag{2}$$

5. Results

Out of 15 experiments, only in nine cases steady states were reached and measured during spring 2019. The experiments were unsuccessful in configuration of low conductive specimens and high $TC_{2\text{-}7}$, where the temperature difference was over the measurable limit.

Results evaluated in the TM are presented in Tab. 3 below. The measurement standard deviation was 0.023 for Closed, and 0.009 for Mean specimens. Although the experiment results were consistent, the measured specimen conductance was much lower than expected.

Tab. 3: TM & OM Specimen conductance measurement results comparison.

Q_{in}	**[W]**	2		4			7	
$TC_{2\text{-}7}$	**[°C]**	-15	15	-15	0	15	-15	0
V3 Closed	**[W/K]**	*0.134*		*0.148*	*0.160*	*0.207*	*0.151*	*0.172*
V3 Mean	**[W/K]**	*0.064*	*0.086*	*0.073*				

6. Discussion and conclusion

The ability of thermal conductance measurement was limited due to high temperature drops on multiple interface surfaces. The TCR effect was confirmed to be the prime origin of the temperature drops. However, its exact value could not be predicted without further elaboration. The heuristic TM method is not applicable in case of the MHS measurement evaluation where the MHS thermal resistance (R_{SPCM}) is not known in advance.

The relationship between the input parameters and experimentally determined TCR values will be examined. Current TM TCR results are to be compared with an appropriate prediction method to produce a representative set of the TCR in the measurement assembly. Refined values will be integrated in the enhanced Model parameters. The enhanced TM is meant to be a standalone application, capable of specimen conductance calculations, based on the initial test condition settings. The knowledge of TCR values is vital for the model functionality. Performed calibration experiments indicated the limits of current method and defined the requirements for the future tests.

Since the TCR effect can be reduced by the application of conductive films or foils (Ando et al., 2014 and Balandin et al., 2008), contact surface treatment will be considered for the future experiments. The thermal conductance measurable range should be increased.

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