23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

THERMO-VACUUM TEST CHAMBER DEVELOPMENT FOR HEAT SWITCH TESTING IN SIMULATED MARTIAN CONDITIONS

J. Mašek*, P. Brožek, M. Horák*****

Abstract: *In the fall of 2014 the Institute of Aerospace Engineering had been awarded by contract to perform Miniaturized Heat Switch testing. The Miniaturized Heat Switch was the unique technology developed by Italian company Aero Sekur for European Space Agency´s missions to Mars. The aim of the project was to develop an innovative but simple experimental thermo-vacuum test chamber to simulate Martian atmospheric conditions. Conditions such as vacuum of 50 Pa absolute, temperatures in the range from −125 °C to + 60 °C and pure CO2 environment of 1000 Pa absolute. The vacuum tightness of the chamber, deep cooling of the specimen under vacuum environment, thermal insulations or heat transfer paths had to be precisely considered. Important decision was to use the liquid nitrogen as the most appropriate cooling medium and copper rods for heat transfer outside the chamber. Later, elementary calibration vacuum-tightness test of the facility showed that the pressure increased from initial value of 220 Pa absolute to 450 Pa absolute within 16.5 hours and thus proved excellent chamber design. Therefore in the future, the test chamber modular design can be easily modified to allow testing of other space equipment in different simulated conditions.*

Keywords: Space technology, Thermo-vacuum test chamber, Martian conditions, Miniaturized Heat Switch, Vacuum-cryogenic insulation.

1. Introduction

Italian company Aero Sekur, on behalf of European Space Agency (ESA), had developed a unique Miniaturized Heat Switch for space applications. The Miniaturized Heat Switch, a key technology for rover mission to Mars, had to keep a temperature of any scientific instrument carried on-board in predefined range.

Our research at the Institute of Aerospace Engineering aimed to develop an innovative but simple experimental thermo-vacuum facility for Miniaturized Heat Switch testing under various simulated operational conditions. Challenging conditions such as vacuum of 50 Pa absolute, temperatures in the range from −125 °C to + 60 °C and pure CO2 atmosphere of 1000 Pa absolute.

The test facility development was the first essential step to perform final Qualification tests of the Miniaturized Heat Switch technology to prove its design and performance in simulated Martian conditions.

2. Miniaturized Heat Switch and test requirements

Miniaturized Heat Switch (MHS), the unique key technology for rover mission to Mars scheduled beyond the 2020 horizon and possibly for further deep space applications, was developed by Italian company Aero Sekur. The Miniaturized Heat Switch was designed to be lightweight (less than 90 g), small in size (diameter less than 50 mm), of simple construction and self-sufficient in energy. It is worth to mention that similar technology had been developed decades ago in the form of mechanical switches which were complex mechanisms big in size as presented in the paper of significant importance (Batteux et al., 2003).

* Ing. Jakub Mašek: Institute of Aerospace Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, Jakub.Masek@vutbr.cz

** Ing. Petr Brožek: S.A.B. Aerospace s.r.o., Purkyňova 649/127; 612 00, Brno; CZ, pbrozek@sabaerospace.com

*** Ing. Marek Horák, PhD.: Institute of Aerospace Engineering, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, horak@fme.vutbr.cz

The significant drawbacks were the bigger weight and the dependence on power supply. The Miniaturized Heat Switch thus represented a true revolution.

The Fig. 1 shows the Miniaturized Heat Switch (MHS). Switch had two interfaces. The cold interface mounted to the heat sink that radiated the excessive heat to outer environment and the hot interface mounted to the scientific instrument. If the Heat Switch hot interface temperature increased above the limit, the actuator closed a contact. And vice versa if the hot interface temperature decreased below the limit, the heat path was closed and the MHS created a thermal insulation to the equipment.

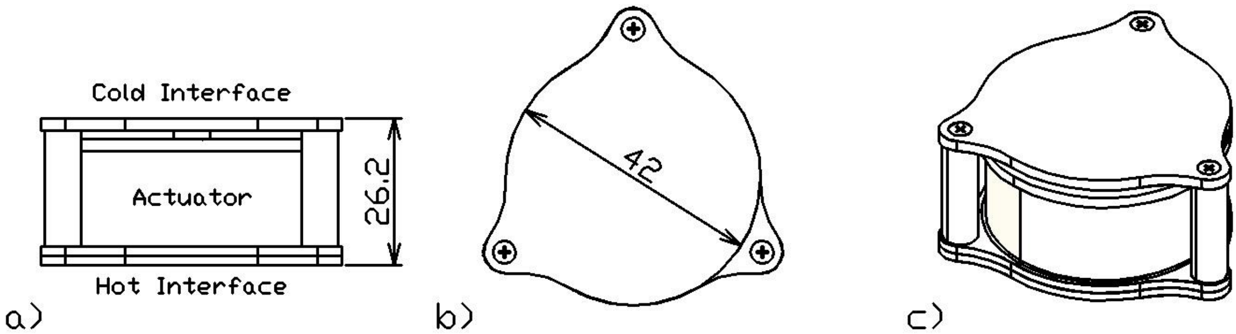

Fig. 1: Miniaturized Heat Switch (a) front b) top c) isometric view; dimensions are in millimeters).

The MHS was designed to keep temperature of any scientific instrument mounted to its hot interface in the range from 15 °C to 25 °C. The temperature range was maintained due to a change of MHS thermal conductivity by two positions of an actuator; position ON – the heat passed away through a radiator and position OFF – the heat generated by any scientific instrument was kept inside. The actuator motion was automatically controlled without any external power supply thanks to thermo-physical properties of paraffin.

According to the Miniaturized Heat Switch predefined performance, Aero Sekur in cooperation with ESA prescribed basic test campaign requirements. The test campaign had to determine whether or not the MHS switched within the specified temperature range as well as its thermal conductivity under different anticipated operating conditions. The first set of conditions was to keep several different constant temperatures on the cold interface and simultaneously to apply predefined heat loads up to 10 W on the hot interface. The second set of conditions was to apply temperature cycles from −125 °C to + 50 °C on the cold interface and −55 °C to + 60 °C on the hot interface to simulate a day/night cycle on Mars.

The test campaign defined strict requirements for the test chamber development. Except achieving the most extreme temperatures there were other requirements: to measure and control temperatures independently on both the MHS interfaces, heat transfers through the MHS and pressure inside of the test chamber.

3. Thermo-vacuum test chamber development:

To fulfill the test campaign requirements we faced the first important question: Would it be cheaper to modify a commercial thermo-vacuum chamber or would it be better to develop a new one?

There had been identified facilities which were suitable for modification to perform desired tests. However these facilities were built for other purposes and therefore were much bigger than needed. The extent of changes to meet the special requirements for the MHS testing would be significant. Even if there was a modified device, the calibration tests would have to be performed anyway. At the end all these aspects meant large expenses.

These facts lead us to idea of designing a new test facility based on the simplest technologies possible to reduce initial and operating costs while the test requirements would be met. Since the Miniaturized Heat Switch was the unique and new technology, the development resulted into an original and tailor-made test facility design consisting of special thermo-vacuum chamber and external supply systems for cooling, heating, vacuum and CO_2 environmental control and data acquisition system for measuring of the temperature and pressure.

However, how to design the thermo-vacuum chamber without prior knowledge of such extreme conditions? We decided to adopt the method of gradual development based on several anticipated hypotheses:

1) Soldered joint between the stainless steel used for chamber walls and copper rods will be vacuum-tight and withstand a load of 10 kg weight at −125 °C on the cold interface.
2) Special stainless steel cylinders and PTFE disks will isolate efficiently the extremely cold copper rods from O-ring sealing used in the grooves of all flanges.

The principle was to define predictions on the basis of which the facility was developed. After the chamber assembly, several initial tests to confirm or reject the hypotheses had been performed and the facility had to be modified accordingly. Therefore a decision that the chamber had to be of modular design was essential.

At that point, the development turned into answering simple question: How to deal with cooling of the cold interface down to −125 °C in the vacuum environment? Liquid nitrogen (LIN) was chosen as the best option. It satisfied both the extreme low temperature limit and easy operation in comparison to the other cryogenic liquids. It became shortly obvious that the initial concepts using labyrinth of pipes to deliver LIN directly into the chamber, LIN regulators and other high-tech pieces of hardware did not represent a cheap and easy way. Moreover there were operational restrictions with the LIN flowing through the capillaries, such as a quick medium evaporation or frozen moisture. Better idea that fitted to the safe low-cost solution was to cool down both interfaces through thermal conductivity rods as shown in Fig. 2.

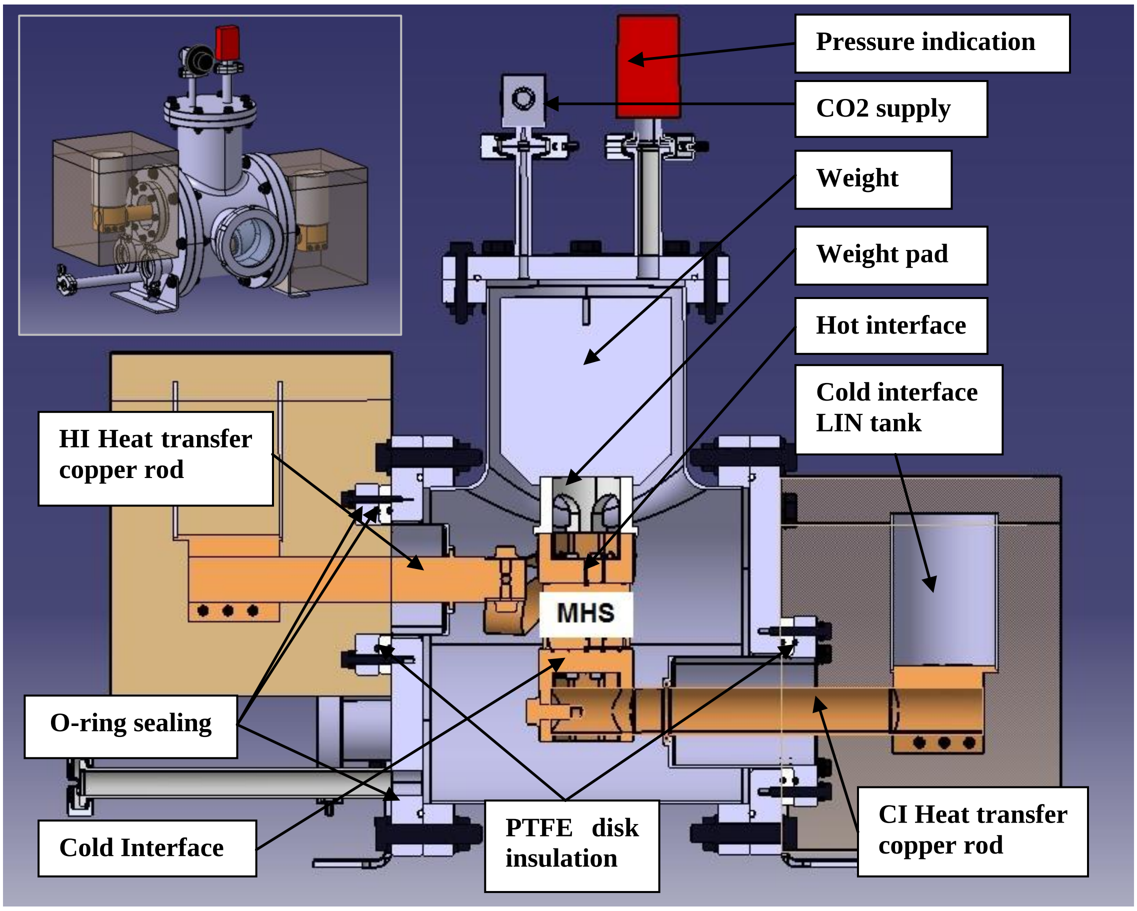

Fig. 2: Thermo-vacuum test chamber cross section.

The development now got to the selection of materials. Inspired by fundamental papers (Lee, 1989 and Jelínek, 1982), three materials were chosen with respect to the market commonality and intended application in the chamber construction: Stainless steel was used for chamber walls predominantly loaded by external pressure; Copper was used for components acting as a heat path and Teflon (PTFE) as a thermal contact insulator in the vacuum environment. Additionally Polystyrene was used outside of the chamber as LIN tanks thermal insulation.

One of the biggest challenges was to ensure a vacuum tightness in cryogenic environment, especially next to the deep cold elements going through the chamber walls. Cheap common O-ring sealing used in the grooves of all flanges did not sustain such a low temperatures and caused malfunction. Therefore special stainless steel cylinders with a wall thickness of 1 mm acting as heat resistors were developed. These cylinders held the pure copper rods by solder joint and were isolated by PTFE disks from the chamber walls. Additionally in this case, the common O-rings were replaced by the PTFE ones.

The solder joints were critical to the chamber design. Mainly because of the stresses that result from the tight connection of two materials with different thermal expansion coefficients, but also because of the mechanical stresses caused by the weight of the whole heat transfer assembly and additional weight above the MHS. Small modifications to improve the joints from both perspectives of soldering technology and joint properties were applied in cooperation with the Institute of Scientific Instruments of the CAS, Brno.

4. Results

Initial chamber tests proved that all Hypotheses were correct. Elementary calibration tests of the chamber showed the pressure increase from initial value of 220 Pa absolute to 450 Pa absolute within 16.5 hours and thus proved the vacuum tightness of the chamber design and particularly the tightness of the soldered joints. This result confirmed the Hypothesis 1). Soldered joint between the special stainless steel cylinder and copper rod close to the cold interface endured the load of 10 kg weight and cooling down to −140 °C.

Wall temperature of the chamber and used O-ring sealing never dropped below 0 °C in any case due to the proper insulation made by special stainless steel cylinders and PTFE disks, this result confirmed the Hypothesis 2).

5. Conclusions

Our concept was intended to be as simple as possible but still able to meet all the challenging requirements. We ultimately considered the use of more automatic control, for example a control of the cooling medium amount or the implementation of long-term computer simulations in the design process, but all of that would increase the expenses significantly. The test facility and especially the chamber modular design could be easily modified in the future to allow testing of other space equipment even in different simulated environments. Internal modification of the interfaces would have to be done.

The presented thermo-vacuum test chamber design proved after the initial load tests exceptional viability and endurance for further improvement. That resulted in one year lasting successful facility calibration tests which have been confirmed by ESA. The first tests of the Miniaturized Heat Switch samples followed in short time after.

Acknowledgement

The research leading to these results has received funding from the MEYS under the National Sustainability Programme I (Project LO1202).

On this place above all I would like to thank Ing. Robert Popela, PhD., the project leader at Institute of Aerospace Engineering, BUT Brno, my colleagues Ing. Petr Brožek and Ing. Marek Horák, PhD. for cooperation. Many thanks also to Ing. Aleš Srnka, CSc. and Ing. Pavel Hanzelka (group of Cryogenics and Superconductivity) and Ing. Ivan Vlček, PhD. (Soldering operator, group of New Technologies) from the Institute of Scientific Instruments of the CAS, Brno for their willingness to help in any situation. My acknowledgement further belongs to Stéphane Lapensée, the ESA project representative (ESA-ESTEC, Noordwijk, The Netherlands) and Giuseppe Bonzano, project leader at Aero Sekur, Italy.

References

Batteux, J.D., Labov, S.E. and van den Berg, M.L. (2003) Electro-mechanical heat switch for cryogenic applications. Google Patents, US Patent 6, 532, 759.

Lee, G. (1989) Materials for Ultra-High Vacuum. Fermi National Accelerator Laboratory, Illinois.

Jelínek, J. and Málek, Z. (1982) Cryogenic technology. Student text, SNTL, Prague (in Czech).