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THERMAL CONTACT RESISTANCE – A POSSIBILITY IN NANOSATELLITE PROTECTION

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ABSTRACT

The thermal contact resistance is a discontinuity in the heat transfer process that generates an abrupt decrease of the heat flow between two surfaces in thermal contact. The phenomenon could be used as an inexpensive and efficient thermal insulation technique. We assume that this technique can become a strategic option for the thermal protection of nanosatellites. In Brazil, an initial study of this possibility is carried out in partnership between the Heat Transfer Laboratory of the Federal University of Rio Grande do Norte (UFRN) and the National Institute of Space Research (INPE).

Keywords: Thermal insulation, Heat transfer, Nanosatellite.

INTRODUCTION

The design of space vehicles is limited by mass, volume and power restrictions (NASA, 2018). It is an especially difficult task to deal with these restrictions when concerning about the thermal management.

To prevent the damage of the integrity of a satellite, there are two sorts of thermal control techniques: passive and active. The passive one are those which uses no energy to operate. Examples of passive techniques are: multi-layer Insulation, thermal coating, heat pipes and sunshades. Unfortunately, consolidated methods of thermal management, common to conventional satellites, could not be directly apply to nanosatellites. Thus, alternative methods should be considerate.

The choice of a secure, light, inexpensive and efficient option to thermal preservation of a nanosatellite depends on the understanding of the relations between the energy coming from the thermal sources and the heat transfer process.

HEAT TRANSFER PROCESSES

Five heat transfer processes (conduction, convection, radiation, phase change and ablation) could be used to preserve the integrity of a space vehicle. We will consider only the basic aspects concerning about radiation and conduction, since these are the main processes of heat transfer in a nanosatellite (ROSSI, 2014). The heat transfer by conduction can be estimated by Fourier's Law:

$$\frac{\delta Q}{dt} = -\kappa . A . \frac{dT}{dx}$$

$\delta Q/dt$ heat transfer rate (W)
κ thermal conductivity coefficient of the material (W/m.K)
A area normal to the direction of heat flow (m²)
dT/dx thermal gradient in the direction of heat flow (K/m)

The heat transfer by electromagnetic waves between two bodies, without a interfering medium, can be estimated by Stefan-Boltzmann Law:

$$\frac{\delta Q}{dt} = \epsilon . \sigma . A . T^4$$

$\delta Q/dt$ heat transfer rate (W)
ε emissivity of the surface (adimensional)
σ Stefan-Boltzmann constant (5.67 x 10^{-8} W/m².K⁴)
A area of the surface (m²)
T temperature of the surface (K)

According to Rossi (2014), when comparing the amount of the contacting surfaces (i. e., submitted to heat transfer by conduction) with the high amount of surfaces exposed to vacuum of the space (at low temperature), it is noticed that the radiation is the predominant process of heat transfer in a nanosatellite. As the heat sources inside a nanosatellite are of low thermal power – not more than 30 W the external sources must be considerate.

The intensity of the solar radiation that reaches the outside Earth atmosphere is almost 1400 W/m² (HOLMAN, 2010).The combination of the thermal radiation emitted by the Earth and its albedo (average value of 0.3), the energy due to the planet that reaches a nanosatellite at low orbit corresponds to radiation with an intensity of 410 W/m². Although this value is 70% less than the intensity of the direct solar radiation, Rossi (2014) consider that it is a major contributor to the temperature changes within a nanosatellite.

Both conduction and radiation could be helpful to avoid thermal damages on nanosatellites. These processes are used in most techniques of thermal management, as the multilayer insulation and optical coatings.

Optical coating is the technique that uses layers of material to cover the surface of the space vehicle in order to change its the radiant properties.

Multilayer insulation it is a technique where a material formed by multiple insulating barriers is used to thermal protection of space vehicles. The insulation effect of the first barrier is added to the second barrier, that is added to the third barrier and so on, resulting in cumulative effect that provide a high performance insulating effect (NASA, 2018; ROSSI, 2014).The conductive heat transfer is mitigated by the successive layers of different materials, each one with low thermal conductivity (k). As the overall thickness of the set is increased, the result is a reduction of the conductive heat transfer.

There is a possibility to improve the thermal insulation of nanosatellites, specifically of the contact surfaces, through the effect of thermal resistance. The thermal resistance of contact is due to the effect of the roughness of the surfaces in contact. The points of contact intersperse with interstices which are, in most cases, filled with air. Thus, the thermal flow will occur due to conduction of heat through the actual contact area and conduction or radiation through the interstices (INCROPERA et al., 2014).

In composite systems, the temperature drop between interfaces may be considerable as a consequence of the thermal contact resistance R_{tc}. For two walls placed in contact, being the areas of heat transfer unit, the R_{tc} is expressed by:

$$R_{tc} = \frac{T_a - T_b}{q_x}$$

T_a temperature of wall surface "a", in the upstream direction of the heat flow (°C)
T_b temperature of wall surface "b", in the downstream direction of the heat flow (°C)
q_x heat flow rate through the wall (W)

Considering the space vacuum, the heat transfer by convection will be discarded. Thus, there remains radiation and conduction to transfer heat between the surfaces in contact at a nanosatellite. As the effective area of the contact points between the surfaces is very small, conduction heat transfer will be of low efficiency and therefore only the radiation process remains. The possibility to apply the thermal resistance effect to improve the thermal insulation of nanosatellites was investigated in the present work.

MATERIAL AND PROCEDURES

A very simple experiment was prepared to observe the effect of thermal resistance between two metallic plates whose surfaces where placed in contact. A copper plate was mounted over a bottom rockwool layer; a steel plate was mounted over the copper plate; a rockwool layer was mounted over the steel plate and a rock block was mounted over the upper rockwool layer. Thermocouples (K – type) were fixed between the bottom rockwool and the copper plate; the steel plate and the copper plate and the steel plate and the heater. In figure 1 is presented the assembly diagram used in the experiment.

Two experiments were conducted: 1) heating of the waffle without copper rolls between the plates; 2) heating of the waffle with copper rolls between the plates of steel and copper. Nine rolls of copper were used, each one with about 10 mm long and 3 mm of diameter. In figure 3 can be seen the copper rolls used to enhance the thermal contact resistance between the plates of steel and of copper. The heater was turned on and the temperatures between the plates were registered. In order to provide mean values of temperatures, each experiment was repeated three times. The assembly of the rolls on the copper plate can be seen in figure 4.

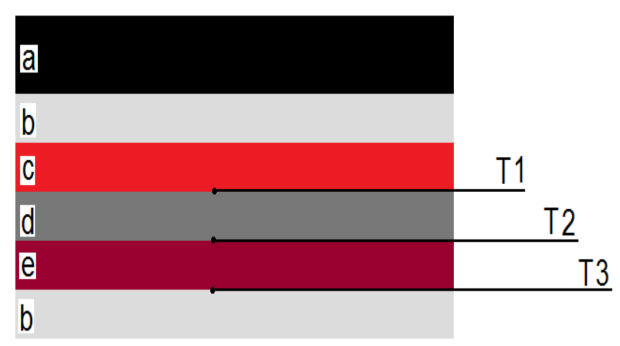


Fig. 1 – The waffle shape of the assembly of the experiment: a – rock block; b – rockwool thermal insulator; c – heater; d – steel plate; e – copper plate.

Fig. 2 – The assembly of the experiment and the temperature meters.

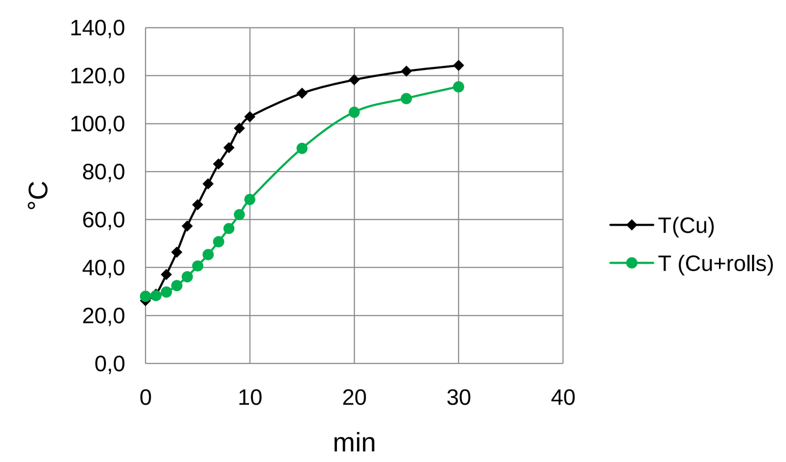
Fig. 3 – The copper rolls.

Fig. 4 – The copper plate with the rolls.

RESULTS AND DISCUSSION

The copper plate temperatures obtained in the experiments are shown in figure 5. As can be observed in figure 5, despite the thermal power was the same in the two experiments, the copper plate reached lower temperatures when the rolls was used to increase the thermal resistance of the contact between the two plates. The mean value of the temperature difference between the two situations was about 13 °C.

Fig. 5 - Temperatures of the copper plate



CONCLUSION

Despite the superficiality of this study, the preliminary results may be considered as a stimulus to the continuation of the research, where more details can be investigated.

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