Sociedad Mexicana de Ciencia y Tecnología Aeroespacial, A. C.

3er Congreso Nacional y Primer Congreso Internacional de Ciencia y Tecnología Aeroespacial

Design Proposal to Develop a System to Monitor Temperature and Cosmic Radiation in CubeSat Life Cycles

Efraín López-Verdugo[1], Ana María Arizmendi-Morquecho[2], Alonso Romero Jabalquinto[3], Bárbara Bermúdez-Reyes[4], José Martín Herrera-Ramírez[5], Rafael Vargas-Bernal[6]

[1] Centro de Ingeniería y Tecnología (CITEC),Universidad Autónoma de Baja California, Tijuana; [2]Centro de Investigación en Materiales Avanzados (CIMAV), Unidad Monterrey; [3]Facultad de Ingeniería Mecánica y Eléctrica,Universidad Autónoma de Nuevo León; [4] Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León; [5] Centro de Investigación en Materiales Avanzados (CIMAV), Unidad Chihuahua; [6] Departamento de Ingeniería en Materiales, Instituto Tecnológico Superior de Irapuato (ITESI). efrain.lopez@uabc.edu.mx[1], ana.arizmendi@cimav.edu.mx[2], alonso.romejoj@uanl.edu.mx[3], barbara.bermudezry@uanl.edu.mx[4], martin.herrera@cimav.edu.mx5, ravargas@itesi.edu.mx[6]

***Abstract*- The present paper presents a design proposal to develop a platform to test current materials identified as thermal and radiation barriers. This system represents an excellent opportunity to advance the development of aerospace material characterization for materials projected for low earth orbit spacecraft. The system encompasses the use of a Geiger counter and 2 thermistors to monitor and evaluate temperature and cosmic radiation isolation. The monitoring system is currently being evaluated to be included in the AztechSat 1, a Cubesat project from San Jose State University in colaboration with the Universidad Autónoma de Baja California, Instituto Politecnico Nacional de Mexico, Agencia Espacial Mexicana and NASA Ames Research Center to be delivered to the ISS aboard Nanoracks Orbital 2 in April of 2014.**

I. INTRODUCTION

One of the challenges in spacecraft design is assuring materials can support changes of temperature and exposure to cosmic radiation [1] while in a space environment. The materials in outer space are subjected to vacuum, bombardment by ultraviolet light, x-rays, and high-energy charged particles (i.e. electrons and protons from solar wind). Most notable, at layers of the atmosphere between 90-800 Km where the atmospheric atoms, ions and free radicals are atomic oxygen in its photo-dissociated state. At altitudes between 160 and 560 Km, the atmosphere consists of about 90% atomic oxygen. Due to Aluminum being a preferred material for CubeSat structures, we must consider the mitigation of aluminum erosion by atomic oxygen in spacecraft structure design. To inhibit aluminum disintegration, protective coating materials must be developed to create radiation barriers to protect CubeSat structures and its interior components. While gold and platinum are highly corrosion-resistant, super-alloys are being developed to allow for a more cost efficient solution to the isolation of thermal and cosmic radiation.

A CubeSat is a type of miniaturized spacecraft for space research. It has a volume of exactly one liter (i.e. 1 cubic decimeter) and per standard CubeSat requirements it shall not weigh more than 1.33 kilograms as an integrated unit. Most CubeSats are designed and built conforming to Specifications written by California Polytechnic State University (Cal Poly) and Stanford University. The proposal to standardize CubeSat design was facilitate universities worldwide the ability to conduct science experiments in space and contribute to space exploration. The experiments platform, AztechSat 1, is projected to be launched on April 2014. Currently, a team of Mexican students, scientists and engineers are developing materials to include aboard the AztechSat 1 project. Two factors of space environment will be in-situ monitored. Cosmic radiation by means of a Geiger counter and thermal radiation as by way of two high precision thermistors mounted in the structure of the satellite [4].

This paper has been divided as follows: In Section 1, a brief introduction on corrosion in aerospace materials and basic concepts on CubeSats is presented. Cosmic radiation sensor is described in Section 2. In Section 3, temperature sensors used to measure changes in temperature in the satellite are described. Finally, conclusions related with this work are given in Section 4.

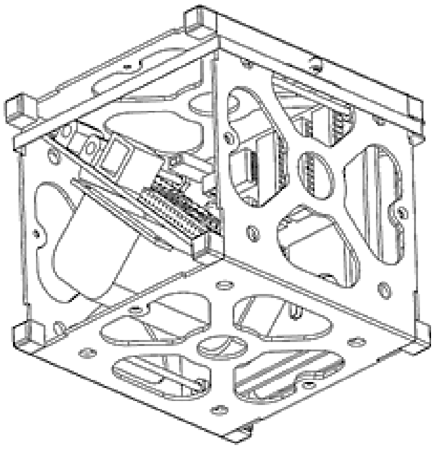

Fig. 1. Basic structure of a CubeSat.

II. COSMIC RADIATION SENSOR

Ionizing radiation is a process in which energetic particles travel through a medium which does not require propagation. It is composed of particles which individually carry enough kinetic energy to liberate an electron from an atom or molecule, ionizing it. It is ubiquitous in the environment, and comes from naturally occurring radioactive materials and cosmic rays. Ionization radiation particles are not directly detectable by human senses, thus instruments such as Geiger counters are required to detect their presence. When ionizing radiation is emitted by or absorbed by an atom, it can liberate an atomic particle (i.e. typically an electron, proton, or neutron, but sometimes an entire nucleus) from the atom.

Geiger-Müller’s tube (GMT) detects cosmic radiation particles in this fashion: a cosmic radiation particle passing through the wall of a GMT will ionize gas atoms in the tube (i.e. cylindrical metal cathode). Electrons produced will be accelerated toward the high voltage sense wire (axial wire anode) that run down the length of the tube, as shown in Figure 2. The central function of the cylinder is distributing the electrical potential and to form a volume in which the electric field is defined by geometry of the electrodes.

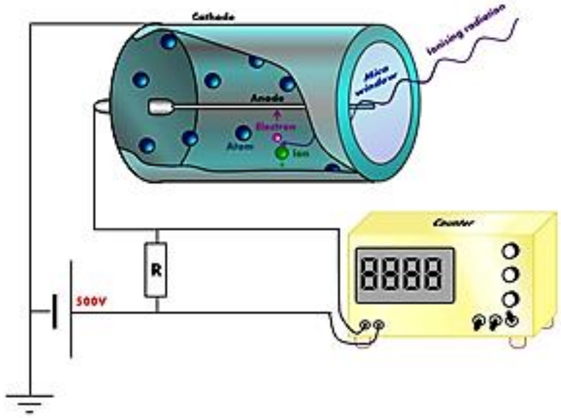

Fig. 2. Mechanism of measurement of the Geiger counter. The voltage applied to the tube allows detecting low energy particles.

The following describes the projected set up for the Geiger counter platform. The set up shall be connected to a high voltage source. The voltage applied to the counter will determine the amount of radiation which can be detected inside the Geiger counter. If the voltage is too low, there will not be enough electrical potential to create a Geiger discharge. On the other hand, if the voltage applied is too high, the Geiger counter will enter to a state of continuous discharge. Thus, a range of ideal voltages to operate the Geiger counter exist and are described in Figure 3., which is called the plateau (see Figure 3). The plateau shown below gives the ideal operational range of voltages.

This type of detector can measure ionizing radiation: emission of nuclear radiation such as alpha particles (two protons and two neutrons bound together into a particle identical to a helium nucleus), beta particles (high-energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei such as potassium-40), and gamma rays (electromagnetic radiation of high frequency and therefore high energy per photon). Such an event can alter chemical bonds and produce ions, usually in ion-pairs, that are especially chemically reactive

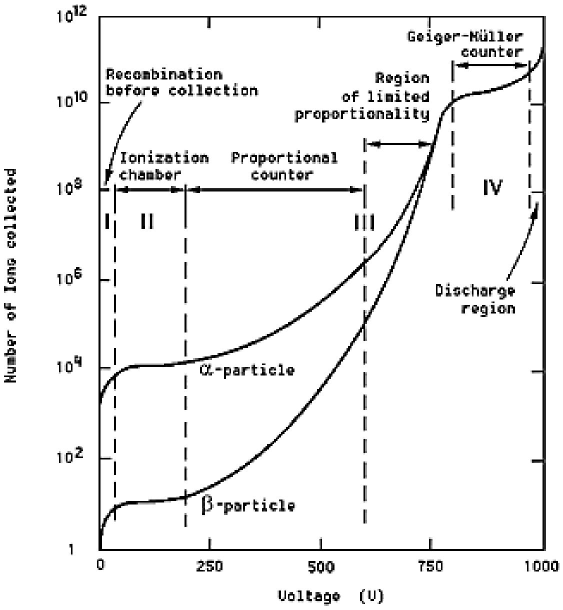

Fig. 3. Plateau region for a Geiger counter. http://felix.physics.sunysb.edu/~allen/252/PHY251_Geiger.html

The projected experiment to be aboard the AztechSat 1 will demonstrate two Geiger counters placed inside of the CubeSat, as depicted in Figure 4. The first counter will evaluate readings after radiation exposure through the protective coating of study, while the second will be directly exposed to the space environment. Both will be subjected to the same type of radiation and both counters will start their operation at the same time. Time intervals will determined the Geiger tubes operational modes.

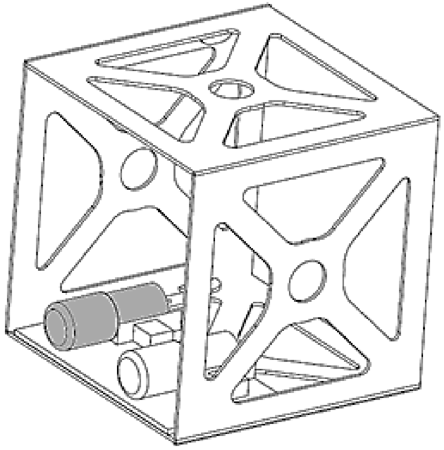

Fig. 4. CubeSat including two Geiger tubes of normal size.

Firstly, this system will measure the amount of radiation absorbed by both Geiger tubes, and electronic voltage substraction will obtain the total contribution of electrons produced in both tubes. The aim is to quantify the efficiency of the thermal and the cosmic radiation barriers. The mathematical expression related with this measurement is given as:

$$\eta = \frac{m}{1 - m\tau} = \frac{m_1}{1 - m_1\tau} - \frac{m_2}{1 - m_2\tau} \tag{1}$$

where m_1 is the number of counts per second of the counter 1 with a coating, m_2 is the number of counts per second of the counter 2 without the coating, and τ is the dead-time of the counter.

III. TEMPERATURE SENSORS

Thermistors are semiconductor materials which vary its resistivity per changes in temperature. Steinhart and Hart in 1968 [5-7] proposed a method that linearizes results for different measurements of resistivity. The relation below is used to linearize acquired reading

$$\frac{1}{T} = A + B\ln|R_t| + C(\ln|R_t|)^3 \qquad (2)$$

where A, B, and C are constants to be determined through a system of equations with three unknowns, R_t is the electrical resistance in ohms, and T is the measured temperature.

A. *Thermal Radiation*

In this case is considered from the outside to inside the CubeSat. The relation which describes the energy emitted for a black body is the Stefan-Boltzmann law [5,7]:

$$Q_{emit} = \sigma A_s T_s^4 \qquad (3)$$

where A_s is the surface area, T_s is the surface temperature, and σ is the Stefan-Boltzmann constant equal to $5.670373(21)\times10^{-8}$ W m^{-2} K^{-4}. But a body with a real surface emits energy according to the relation:

$$Q_{emit} = \varepsilon\sigma A_s T_s^4 \qquad (4)$$

where ε is known as emissivity which is particular for each material and $0 < \varepsilon < 1$.

The use of thermistors consists in determining two measurements, one for the surrounding temperature and other for the temperature of the object to be studied, in according with the relation:

$$Q_{emit} = \varepsilon\sigma A_s\,(T_{so}^4 - T_{si}^4) \qquad (5)$$

where T_{so} is the environment temperature and T_{si} is the temperature of the object.

B. *Conductive Heat*

The total heat that is transferred from the sun to the CubeSat could be measured by using the Fourier law for transfer heat [6]:

$$Q_{con} = kA\frac{(T_1 - T_2)}{\Delta x} \qquad (6)$$

where the transferred heat depends of the difference of temperature measured by the thermistors, A is the contact area, Δx represents the thickness of the material and k is the thermal conductivity coefficient of the material, as shown in Figure 5.

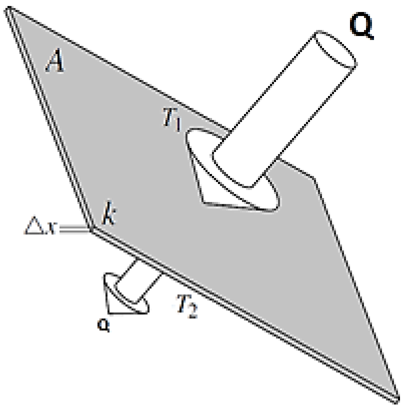

Fig. 5. Heat transfer mechanism to determine thermal radiation into CubeSat.

The thermal conductivity coefficient k needs a benchmark value form experiments here in Earth. The thermal conductivity value will be set through experimentation before the projected launch of the AztechSat 1 CubeSat. The system to determine k here on Earth is called the divided bars experiment.

The ground test design consists in three cylindrical basrs made of aluminum to be used as a reference. One of the bars will be paired with the protective coating. The insulating material needs a thermal coefficient less than 0.046 W/(mK) to reduce the relative error. The test shall run at temperatures lower than 50 Celsius degrees. A heat source must be applied from sample 1 (it is not illustrated in Figure 6), which is expressed as [6]:

$$K_M = \frac{Z_4 - Z_3}{T_4 - T_3}\left[\frac{K_{R1}}{2}\left(\frac{T_2 - T_1}{Z_2 - Z_1}\right) + \frac{K_{R2}}{2}\left(\frac{T_6 - T_5}{Z_6 - Z_5}\right)\right] \quad (7)$$

where Z_i represents thickness of the material i-th, T_i are temperatures between materials, K_R is the thermal conductivity coefficient of reference material, and K_M is the thermal conductivity coefficient of the sample material whose value is unknown. It can be simplified when two samples of material present the same coefficient k to:

$$K_M = \frac{K_R}{2}\left[\Delta T_1 + \frac{\Delta T_3}{\Delta T_2}\right] \qquad (8)$$

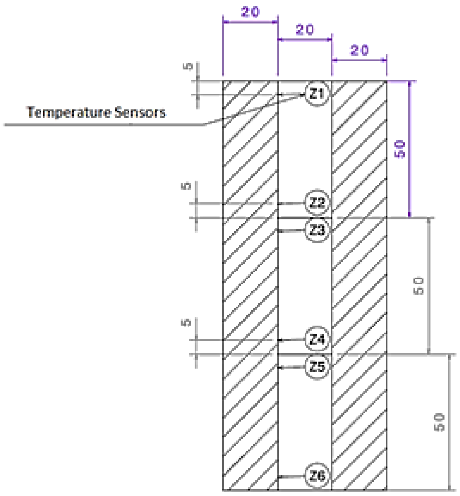

Fig. 6. Preliminary design of the concentric bar cuts used to determine the coefficient of thermal conductivity with dimensions in millimeters.

Fourier law can be applied to a pair of thermistors, with the aim of measuring the total quantity of heat transfer which penetrates to the wall that has been coated by a thermal barrier (see Figure 7), by using the following relation:

$$Q_{wall} = kA\frac{(T_1 - T_2)}{\Delta x} - k_M A\frac{(T_1 - T_2)}{\Delta x} \qquad (9)$$

where T_1 and T_2 are temperatures outside and inside of the nano-satellite, k is the thermal conductivity coefficient of the aluminum and k_M is the thermal conductivity coefficient of the aluminum that has been coated, and Δx is the thickness of the wall of aluminum.

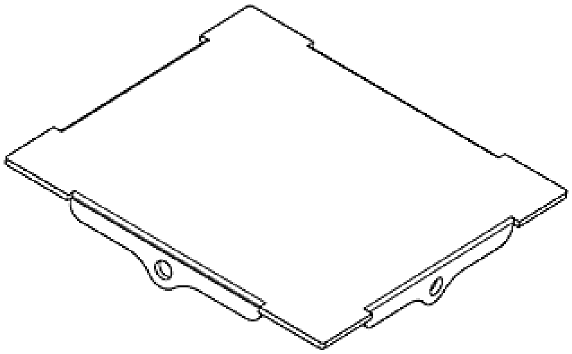

Fig. 7. Face of the AztechSat where both thermistors will be placed to measure the heat transfer that thermal barrier dissipates (on in the top side, the other in the bottom side).

IV. CONCLUSIONS

This proposal is projected to be aboard the AztechSat 1. The use of Geiger counter and a pair of thermistors is proposed as an in-situ measurement system with the aim of improving materials for the growing CubeSat building community. The use of CubeSats represents an opportunity for universities worldwide to perform space science and exploration. Furthermore, this platform demonstrates materials by Mexican researchers and informs of the growing aerospace interest of Mexico.

ACKNOWLEDGMENT

This work was supported by the National Council of Science and Technology of Mexico (CONACYT) within support to Aerospace Science and Technology Network called in Spanish RedCyTE.

REFERENCES

[1] R. Sandau, H.-P. Röser, and A. Valenzuela, *Small Satellite Missions for Earth Observation: new Developments and Trends.* Heidelberg, Germany: Springer, 2010.
[2] J. D. Goldader and S. Choi, "An Inexpensive Cosmic Ray Detector for the Classrom," *The Physics Teacher*, Vol. 48, pp. 594-597, December 2010.
[3] T. Stanev, *High Energy Cosmic Rays*, Second Edition, Chichester, UK: Springer, 2010.
[4] J.W. Gooch and J.K. Daher, *Electromagnetic Shielding and Corrosion Protection for Aerospace Vehicles*, New York, NY: Springer, 2007.

[5] J. S. Steinhart, Stanley R. Hart, Calibration curves for thermistors, Deep Sea Research and Oceanographic Abstracts, Vol. 15, No. 4, pp. 497-503, August 1968.

[6] L. Lira, et al., “Sistema de Medición de la Conductividad Térmica de Materiales Sólidos Conductores, Diseño y Construcción,” *Memorias del Simposio de Metrología*, pp. 1095(11), Santiago de Querétaro, México, 22-24 Octubre de 2008.

[7] M.F. Modest, *Radiative Heat Transfer*, Third Edition, Oxford: UK, Elsevier, 2013.

3er Congreso Nacional y Primer Congreso Internacional de Ciencia y Tecnología Aeroespacial

"Vinculando Investigación, Educación e Industria Tecnológica para el Desarrollo Aeroespacial"

El Congreso Internacional de Ciencia y Tecnología Aeroespacial Jalisco 2013
Otorga la presente

CONSTANCIA

a

Arizmendi-Morquecho Ana María

Por la presentación oral del trabajo aceptado en el comité evaluador de este congreso, realizado del 18 al 22 de Noviembre 2013, en las instalaciones del Hotel Crowne Plaza Guadalajara.
Zapopan, Jalisco.

Luis Valtierra Glez.
Ing Luis A. Valtierra González Madrid
Presidente del Consejo
Aeroespacial de Jalisco

Mendieta
Dr. Fco. Javier Mendieta Jiménez
Director General
Agencia Espacial Mexicana (AEM)

M. en C. Sergio Viñals Padilla
Presidente de la SOMECYTA