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Review Article

A REVIEW ON EVALUATION OF THE DEFORMATIONS INDUCED BY SOLAR RADIATIONS ON SOLAR PANEL FRAME

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Thermal effects on structure of solar panels exposed to solar radiation are significant and complicated. Furthermore, the temperature variation within a year may result in damage in frame structures with covering glass considering the solar radiation. The aim of the present paper is to evaluate deformation state due to temperature on photovoltaic modules surface. Laboratory measurements were carried out employing single grid strain gauges, in order to determine stress in significant points of four different samples subjected to temperature variations. Finally results were analyzed and compared, in order to characterize the performances expected from photovoltaic panels and to prevent cell breaking.

Keywords: Evaluation, Solar Panel, Strain Gauges, Thermal Deformation

INTRODUCTION

With the gradual depletion of fossil fuels in our planet, the application of solar energy becomes very popular currently in the world. Solar energy can be directly utilized through a variety of devices such as solar collectors or photovoltaic cells as shown in Figure 1.

Solar cell is one of the crucial components inphotovoltaic systems. At present, substrate crystalline silicon solar cells with clear cover glasses are widely used in photovoltaic systems. The solar panels are made of semiconducting materials including mono crystalline silicon, polycrystalline silicon and gallium arsenide. The high transmittance glass cover is pressed together withthe panel through silicone rubber, which provides a strongprotection for the core solar cells.The panel consists of asupport frame, a back board made from honeycomb sandwich material, and solar cells installed on the back board which are covered by glass fiber sheet Figure 2. The material of support frame and yoke is always different from the back board.

Evaluation of solar panel deformations on different points, from the center to the edges, over the cells or the gaps, by the frame or along the electrical connections, allows to identify the most critical zones, which must

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Figure 1: Solar Panel Set Up

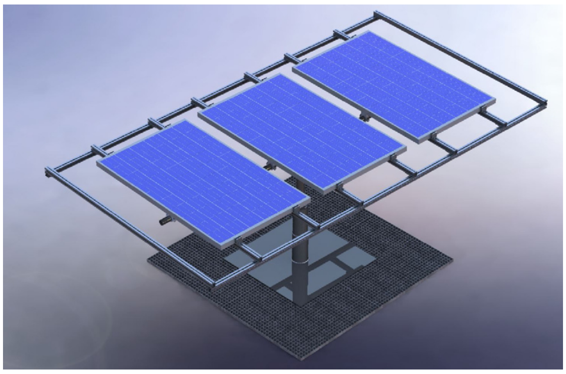
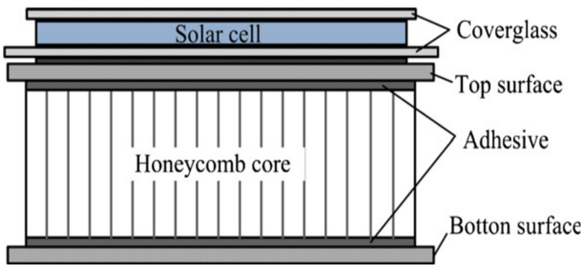
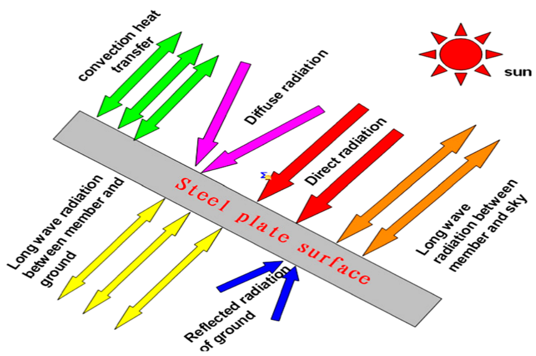


Figure 2: Sectional View of Solar Panel



be improved in order to avoid structural damages. A careful selection and a correct assembling of materials are very important for applications of solar pane systems because the solar panel is the thing that exposed to solar radiation as shown in Figure 3.

Figure 3: Heat Flow Schematic Diagram of Plate Surface



Due to the effect of solar radiation, the temperature of this solar panel is significantly high. Therefore, the thermal stress and thermal deformation inthese structures are larger and more complicated than those which the solar radiation cannot irradiate. Also due to this expansion in day sun light and contraction at night a stresses are induced in frame materials which results in failure or breakage of covering glass.

LITERATURE SURVEY

Buratti C and Goretti M studied the Experimental Evaluation and Mapping of the deformations induced by thermal stress on Photovoltaic Panels.The aim is to evaluate deformation state due to temperature on photovoltaic modules surface. Laboratory measurements were carried out employing single grid strain gauges, in order to determine stress in significant points of four different samples subjected to temperature variations. Experimental data were used to draw thermal expansion maps, to predict the highest stress values, according to materials and assembling. Finally results were analyzed and compared, in order to characterize the performances expected from photovoltaic panels and to prevent cell breaking.

Hongbo Liu, Zhihua Chen and Ting Zhou studied theoretical and experimental study on the temperature distribution of H-shaped steel members under solar radiation. Thermal effects on steel structures exposed to solar radiation are significant and complicated. Furthermore, the temperature variation within a year may result in damage in steel structures considering the solar radiation. The temperature distribution of H-shaped steel members was investigated through a systematic experimental and theoretical study in the case of solar radiation. First, an H-shaped steel specimen was designed and its temperature distribution under solar radiation was obtained by a test. After that, a numerical method was proposed to obtain the temperature distribution under solar radiation. This method was based on transient thermal analysis and the analytical result was verified by the above experimental result. Furthermore, a parametric study was conducted to investigate the influence of various solar radiation parameters and orientation of H-shaped steel members on the temperature distribution under solar radiation. Finally, a simplified approach was developed to predict the temperature distribution under solar radiation. Both experimental and numerical results showed that the solar radiation had a significant effect on the temperature distribution of H-shaped steels. Considering the solar radiation, the temperature of the specimen is about 20.6C higher than the surrounding ambient air temperature. The temperature distribution under solar radiation was observed to be sensitive to the steel solar radiation absorption and orientation, but insensitive to the solar radiation reflectance.

Xiaoyan Wang, Hongbin Geng, Shiyu He, Y O Pokhyl, K V Koval studied the Effect of thermal expansion coefficient on the stress distribution in solar panel. Residual thermal stress, which affects structural safety, would be produced in the solar panel under the temperature field because of the multilayer structure of the solar panel. The stress distribution and the effect of thermal expansion coefficient on the stress of the solar panel under the temperature field using analytic method were studied. The analytical results showed that the maximum of structural tensile/compression stress and shear stress present in the layer of polyimide film and silicone rubber which bonded carbon fiber composite and polyimide film, respectively. The maximal stress value in the structure was decreased remarkably by choosing to use polyimide film with lower thermal expansion coefficient. The one dimensional model used in this work would exert an important influence on the design and structural optimization of the solar panel.

E V Morozov, A V Lopatin studied a novel design of the composite structural lattice frame for the spacecraft solar arrays are presented in the paper. The frame is composed of two flat lattice composite plates assembled into the three-dimensional panel using frame-like connectors. Design, fabrication, modeling and modal analysis of the panel solar arrays based on the proposed technology are discussed. The lattice panels are modeled as three-dimensional frame structures composed of beam elements subjected to the tension/compression, bending and torsion using the specialized finite-element model generator/design modeler. Results of the calculations of the frequencies and vibration forms for the lattice panels with various types of supports imitating the ways the panels can be attached to the spacecraft body, deployment must, and adjacent solar panels are presented and discussed. The lattice frame design for maximum fundamental frequency is performed subject to constraints imposed on the geometrical parameters of the solar panel.

E V Morozov, A V Lopatin studied nonlinear analysis of the deformation of a thin flexible composite membrane stretched on a rectangular cell of the spacecraft solar array frame is presented in the paper. The frame of the array and the thin flexible membrane stretched on this frame are designed to be capable of withstanding the transverse mechanical loadings exerted on the structure during the delivery to orbit and deployment. The governing nonlinear equations modeling the pre-stretched flexible orthotropic membrane are solved using Galerkin method. Results of calculations are compared with those based on finite-element modeling. The comparisons have demonstrated efficiency of the proposed approach to the analysis and design of composite solar arrays featuring orthotropic composite flexible membranes. The parametric analyses were performed for various combinations of the g-force, mass of the photovoltaic elements and dimensions of the solar array.

THEORY

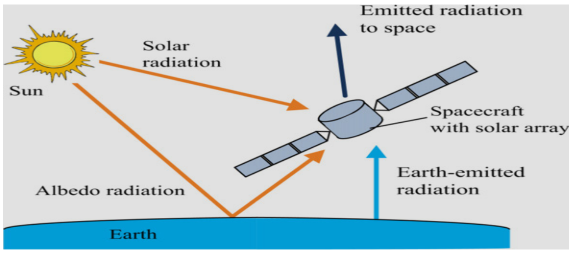
Solar arrays are critical appendages which provide primary power sources for spacecraft. When the spacecraft is traveling around the Earth, the solar arrays experience periodic heating and cooling in the sunlight and shadow region of the Earth with the variation of the thermal environment. Dramatic temperature changes occur at day–night and night–day transitions in the orbit. Sudden heating changes on a surface of an appendage may induce temperature gradients that generate time-dependent bending moments. These moments induce the structure deformations and vibrations of solar arrays, which influence the energy efficiency and reliability of on-orbit spacecraft. Therefore, thermal analysis of solar arrays is of great importance for the safety operation of spacecraft. Much research on the thermal analysis and thermal-structure response of solar array and other appendages has been carried out. Foster and Tinker compared the flight data and computer simulation results of the solar array for Hubble Space Telescope, and pointed out that the source of the disturbances was the thermally driven deformation of the solar arrays in conjunction with frictional effects in the array mechanisms. Thornton *et al*., have done much research on the Hub-ble Space Telescope solar array including coupled and uncoupled thermal-structure analysis of booms and blankets. Johnston and Thornton studied the thermal-structural performance of rigid panel solar arrays. Song et al. developed a comprehensive structural model of composite spacecraft booms and studied the thermally-induced flexural oscillations. Xue *et al*., discussed the temperature field of thin-walled tube elements for transient thermal-structural analysis of large-scale space structures based on finite element method, and expounded the necessary condition of thermally-induced vibration and the criterion of thermal flutter. Yang *et al*., provided a method to calculate the temperature response of folded solar array. Li *et al*. performed the characteristics of the transient temperature field in the simplified rigid solar array. Foster and Aglietti focused on the thermal environment and the response of the multifunctional structures, the temperature of this structure was analyzed by developing a numerical model, and the possible thermal control solutions were discussed either. However, the previous research focused on the key components like beams or panels of the large space structures, but few discussed about the temperature field of the whole solar array.

However, because the solar array is a complicated space structure, including panels, beams and joints which have different material characteristics, the thermal exchange and coupling among its components and the space environment should be considered. The flight data indicated that the composite structures of the solar array have remarkable influence on its temperature and deformation. Therefore, it is necessary to analyze the transient temperature field of the whole solar array accurately. Nodal network method and finite element method (FEM) are the most common tools used for thermal analysis of the spacecraft and its appendages. Discrete mathematics model and finite difference technique are used in nodal network method to solve the temperature distribution. The nodal network method has strong practicability dealing with the thermal problems, but it is difficult to solve the complex structures considering complicated boundary conditions. In contrast, FEM has many advantages for the thermal analysis of space structures. For instance, the interpolation technique considering physical properties with the change of the temperature can be used to reveal more accurate resolutions, and the structure model can be combined into the thermal analysis model to calculate the temperature distribution. A thermal analysis model of a composite solar array with complex structures is developed to characterize the thermal response of the whole solar array system subjected to space heat flux. First, the view factors of orbiting solar array in low Earth orbit and geosynchronous orbit are proposed according to its flight attitude based on the thermal environment. Then the thermal analysis model for the complex solar array is developed, in which the influence caused by honeycomb panel, simplified hinges, composite frames and yokes are involved. The transient temperature fields in different orbits of all the components are studied by using the model. Furthermore, the thermal response of the solar array with two commonly used materials is contrastive analyzed.

Thermal Environment of the Solar Array

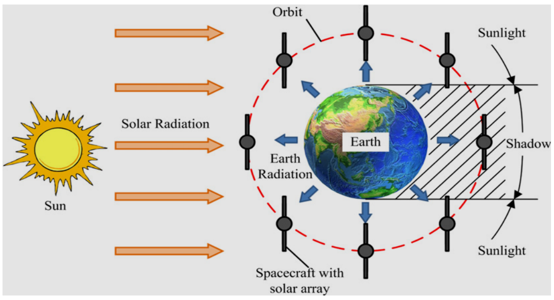
The orbiting spacecraft and its solar arrays may be heated by space environment and multiple heat sources. The Sun and Earth are the primary heat sources. The main thermal environment of solar array includes: direct solar radiation, Earth-emitted radiation and Earth-reflected radiation. Meanwhile, the solar array may be heated by other planets, or may have thermal exchange with the module and other components of the spacecraft. But compared with the main heat sources, they are small enough to be ignored. Moreover, the solar array also emits heat radiation to deep space. The typical thermal environment of solar array is shown in Figure 4.

Figure 4: Thermal Exchange between Spacecraft (Solar Array) and Space



According to the mechanical structure of the solar array, a distinguishing feature is that the attitude of solar arraycan be regarded as tracking and catching the Sun irrespective ofthe orbit inclination. So the normal of the surface towards the sunlight is always parallel to the solar radiation vector. The thermal environment of the solar array in circular orbit is shown in Figure 5.

Figure 5: Schematic of Thermal Environment of Solar Array in Orbit



Calculation of the External Heat Flux and Effective Thermal Conductivity

External Heat Flux

The solar flux S is approximately 1353 W/m2. The solar flux received by a surface is given by

$$q_s = S\alpha_{eff}\cos\theta \quad ...(1)$$

Where

θ = the angle between the solar vector and the normal of the surface.

α_{eff} = is the effective solar absorptivity of the anodic surface of solar array.

For solar array, the angle θ equals to 0, α_{eff} is determined by incident photon to-electric conversion efficiencies, packing factor and solar absorptivity.

It is expressed as

$$\alpha_{eff} = \alpha_{sc}\eta_p + \alpha_{sb}(1-\eta_p) - \eta_w\eta_p \quad ...(2)$$

Where

η_w= the conversion efficiency.

η_p= the packing factor.

α_{sc}= the solar absorptivity of the solar cell surface.

α_{sb}= the solar absorptivity of the surface between the solar cells.

Effective Thermal Conductivity

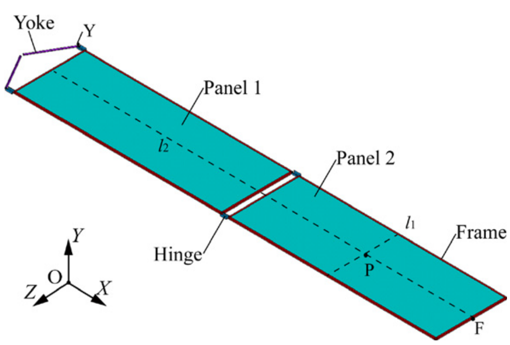
The effective thermal conductivity is given by the equation

$$K_e = K_f\frac{\Delta A}{A} + K_g\left(1-\frac{\Delta A}{A}\right) + k_r \quad ...(3)$$

Considering the thermal environment of the solar array, the heat exchange between space and panels is more significant than that between panels. So the gas thermal conductivity (k_g) and the radiant effective conductivity (k_r) are negligible. The effective thermal conductivity is simplified to

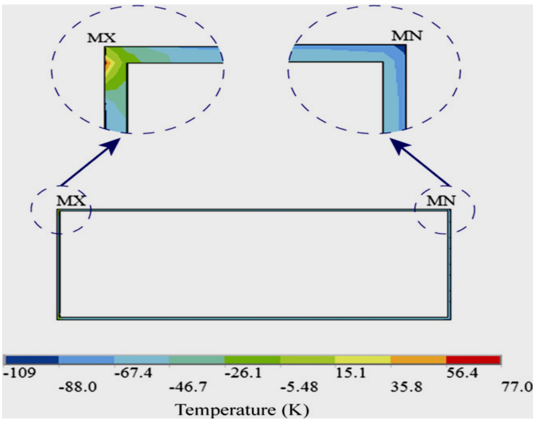
$$K_e = K_f\frac{\Delta A}{A} = \frac{2\sqrt{3}}{3}\frac{t}{l}K_f \quad ...(4)$$

Figure 6: The Thermal Analysis Model of a Typical Solar Array



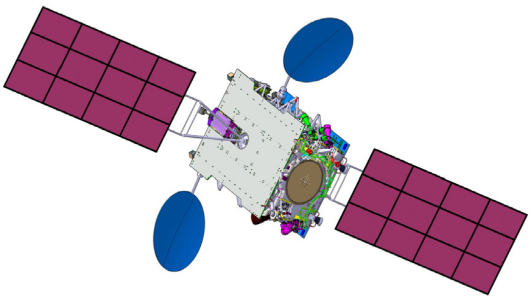
Substantial improvements in the design of space solar arrays have been made by introduction of the thin-film stiffened panels (FITSs).

Figure 7: Temperature Field of Frame in Normal Thermal Environment



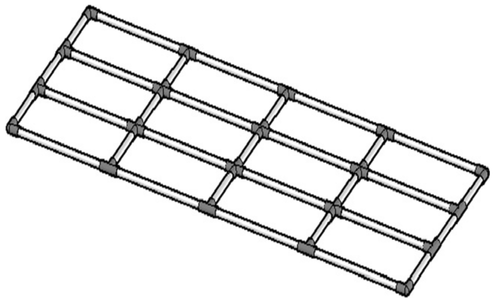
Thin film photovoltaic (TFPV) solar arrays offer the potential for providing a higher level of power generation in a lightweight configuration that can be compactly stowed for a space launch. A typical solar wing design is shown in Figure 8.

Figure 8: Spacecraft with Solar Arrays



The frame of the array and the thin flexible membrane stretched on this frame should be capable of withstanding the mechanical loadings exerted on the structure during the delivery to orbit and deployment. Advanced high-modulus, high-strength carbon fibre reinforced polymers (CFRPs) are normally implemented in current designs. One of the typical configurations of the solar array frame is assembled from the CFRP thin-walled tubes joined with the metal fittings-connectors (Figure 9).

Figure 9: Solar Array Frame



The thin flexible membrane is stretched on the frame and fixed to the tubes. Then the photovoltaic cells are attached to the surface of the stretched membrane. In the most of the designs, the deployable solar arrays are stowed folded and could be deployed in various configurations. When stowed, they are usually placed parallel to each other and compactly packaged for launch. During the delivery to orbit, the membranes are subjected to the transverse g-force. The resulting pressure is equal to the product of the weight-per-unit-area of the membrane with the photovoltaic elements attached by the g-force. As a result of this loading the flexible membrane deflects. The excessive deflection could lead to the damage of the photovoltaic cells and/or electrical circuits. For this reason, one of the design requirements is that the deflection of the membrane should be limited to some specified value.

The design of the solar array implies the solution of two interrelated problems. The first one involves the strength and buckling analyses of the frame and normally requires the use of a finite-element method. Based on the results of these analyses, the parameters of the thin-walled CFRP tubular rods can be found. The second problem is related to the analysis of the deformation of the flexible membrane stretched on the frame and subjected to the transverse load. The solution of this problem provides the geometric parameters of the membrane and stretching forces delivering the allowable level of deflection prescribed by the design specifications. Based on this information, the required number of the internal tubular rods can be identified. For given overall size of the frame, the distances between these rods in the frame can be calculated. These dimensions and the values of pre-stretching membrane forces need to be used as part of the input data for the design analysis (strength and buckling) in the first problem. Joint solution of these problems delivers the design of the solar array. The solution of the second problem related to the non-linear deformation of the flexible membrane carrying photovoltaic elements is presented in this paper. The problem is formulated for the orthotropic flexible membrane subjected to the transverse uniform pressure and tensile in-plane forces applied to the edges of the membrane. The deformation of the membrane is modelled by the system of non-linear differential equations. This system is reduced to the governing system of three equations presented in terms of the in-plane displacements and deflection. The first studies of the non-linear deformation of isotropic membranes under transverse loading have been performed by Föppl and Föppl and Prescott. However, they did not consider the in-plane pre-stretching. In this work, the solution of the governing system of non-linear differential equations has been obtained using Galerkin method. The membrane in-plane displacements and deflection were approximated by trigonometric functions. Based on this approach, the algebraic cubic equation with respect to the deflection value at the centre of membrane has been obtained. Solution of this equation provides an analytical formula for the calculation of the membrane deflection at the central point. Using this formula, the calculation of the deflections have been performed for isotropic and orthotropic flexible membranes having different geometry parameters and subjected to different levels of loads. The results have been verified using comparisons with the finite element solutions.

Decay of solar panels depends not only on chemical action of pollution and atmospheric agents, but also on thermal stress caused by solar radiation. Evaluation of photovoltaic modules deformations on different points, from the center to the edges, over the cells or the gaps, by the frame or along the electrical connections, allows to identify the most critical zones, which must be improved in order to avoid structural damages. A careful selection and a correct assembling of materials are very important for applications of photovoltaic systems, such as their integration in building components and noise barriers.

Due to the effect of solar radiation, the temperature of these solar panel structures is significantly higher than the surrounding ambient airtemperature in summer, and the temperature difference between frame and ambient air may exceed a value of 20°C. In addition, the temperature of frame structures is non-uniform under solarradiation. If a frame structure is constructed in summer, its temperature change may exceed a value of 80°C inwinter. For this temperature change, the thermal stress is induced in solar panel frame structure. Therefore, the panel willfail or fracture because of deformation considering the temperature change in addition toother loads, such as gravity and wind load. Also deformation results in damage of covering glass as shown in Figure 10.

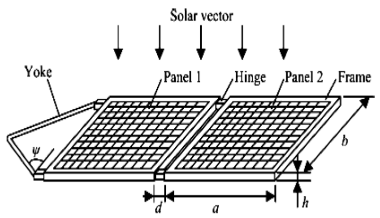
Figure 10: Damaged View of Covering Glass

METHODOLOGY

Proposed Methodology

Solar panels are subjected to thermal stress due to solar radiation as shown in Figure 11, variable on different points of the module, which produces a particular deformation state.

Figure 11: Damaged View of Covering Glass



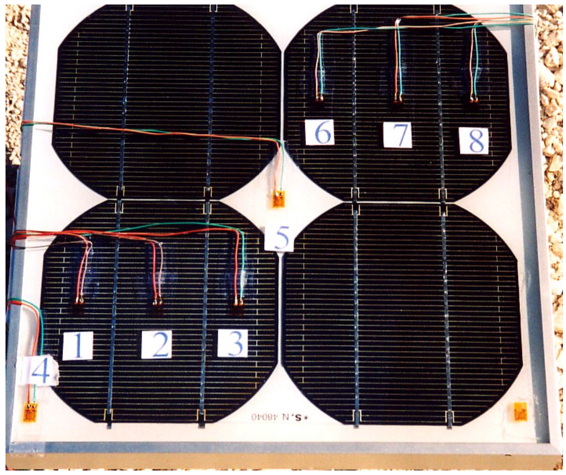
In the present paper an experimental evaluation of deformation state due to temperature variations on photovoltaic panel's surface. Paper is a part of a work concerning thermal performances of photovoltaic modules. In working conditions, photovoltaic cells are subjected to a thermal gradient between the two sides of the panel, due to solar radiation. The aim of the present work is to prevent damaging of different components by identifying the most strained points. It consists in laboratory extensometric measurements on specimen's front side, the one directly exposed to the sun in working conditions. Four different photovoltaic modules were subjected to temperature cycles into a climatic chamber and deformation measurements were carried out employing strain gauges, glued on the samples surface. Electrical strain gauges are constituted by metal single grid on a plastic support. In order to eliminate extensometric grid influence, relative measurements were carried out, using a reference material (titanium silicate), whose thermo physical properties are known. The thermal expansion coefficients were calculated, for each panel, on eight significant points, selected on front side, and the corresponding deformations, induced by thermal variation, were then evaluated. Finally, considering geometric and materials symmetry of samples, maps of thermal expansion on the specimens surface were drawn. Laboratory tests provided the deformation state of photovoltaic panels at standard working temperatures (20 to 60°C) and are preliminary to outdoor measure- ments, where thermal conditions are uncon- trolled and variable.

EXPERIMENTAL WORK

Samples and Facility

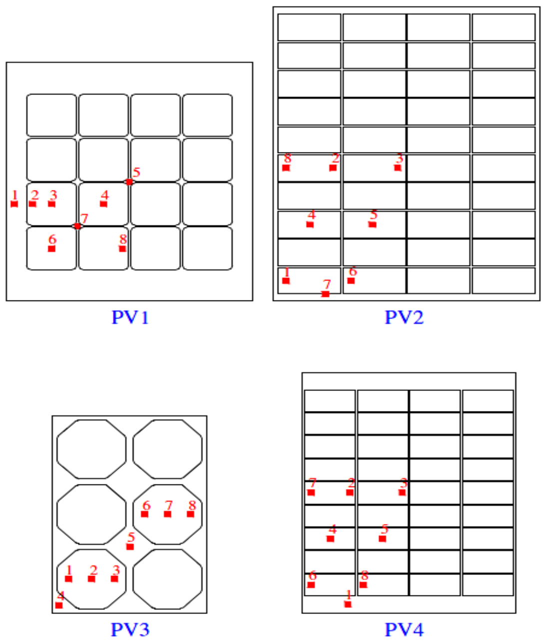
Four samples of photovoltaic modules were examined, with different dimensions, shapes, cells (mono-crystalline or polycrystalline silicon), protection and support materials (Plexiglas, Tefzel, Tedlar), with or without frame. In particular, sample PV1 has Plexiglas front sheet with high thermal expansion coefficient, whereas samples PV2, PV3 and PV4 are provided with transparent Tefzel and aluminium frame; only PV2 has polycrystalline silicon cells. Photovoltaic panels were furnished by different companies. In previous experiences each sample was verified at electrical insulation and functionality with different resistances, before and after accelerated aging process, by thermo hygrometric stress in climatic chamber; they showed regular performances in each check. Experimental facility consists in a climatic chamber, sensors and acquisition devices for deformation and temperature measurements. Deformation measurements methodology is based on extensometric theory. Single grid electrical strain gauges were chosen; previous measurements, carried out with rectangular three grid strain rosettes, showed in fact an isotropic behavior in each point.After control of samples in order to verify absence of defects, strain gauges were glued on eight different points, one for each channel of the acquisition unit, on the photovoltaic panel's front side (Figure 12).

Figure 12: Strain Gauges Glued on PV Sample



Strain gauges arrangement was determined in order to evaluate thermal performances of photovoltaic modules in all the parts that compose the front side. Therefore the eight strain gauges were placed in significant zones, such as geometric centre and edges of photovoltaic cells placed in, gaps uncovered by cells, metallic conductors for electrical connections, etc. The arrangement of strain gauges on samples is shown in Figure 13.

Figure 13: Arrangement of Strain Gauges on Samples Surface



In order to measure the actual temperature on the specimens front side, type PT100 DIN-A thermo-resistances were used (accuracy: ± 0.15°C at 0°C and ± 0.35°C at 100°C). Contacts between thermo-resistances and surfaces were obtained with thermo-dissipative paste.Strain gauges fixed on the photovoltaic panel are subjected to a deformation in the sensor grid, due to the thermal variation on the sample surface; as electrical resistance increases, deformation increases too. Finally, being the module free from ties, sample is thermally expanded without strain variations.

Thermal expansion coefficient of a sample can be calculated knowing the strain gauge gain factor *F* and measuring both specific variation of electrical resistance $\Delta R/R$ and temperature difference ΔT. The electrical resistivity of metallic grid varies with temperature; its thermal expansion coefficient is different from the one of sample, so extensometric grid is also mechanically deformed.

Calculation of samples real deformations was possible using twin strain gauges (same type and same manufacture), glued one on photovoltaic module and one on a silica-titanium bar, the thermal expansion coefficient of which is known. A relative measurement is carried out, in order to purge data from error due to grid thermal expansion. Strain gauges were connected to acquisition unit according to the 1/2 Wheatstone bridge model, for a direct reading circuit. Tests were carried out in the climatic chamber and permitted to evaluate for each sample the thermal expansion coefficient in the eight significant points of the sample. Considering a temperature variation D*T*, the thermal expansion coefficient is given by

$$\alpha_S = \alpha_R + \frac{\varepsilon_{(G/R)} - \varepsilon_{(G/R)}}{\Delta T} = \alpha_R + \frac{\Delta\varepsilon}{\Delta T} \qquad ...(5)$$

Where α_R is 0.03 $\times 10^{-6}$ °C^{-1} in the thermal range –45°C to +175°C.

Before deformation measurements, check of strain gauge signal stability and elimination of residual stress. Deformations measurements were carried out in climatic chamber, where a typical temperature cycle in working conditions was simulated:

- 4 hour maintenance at 20°C;
- 6 hour heating from 20 to 60°C;
- 4 hour maintenance at 60°C;
- 6 hour cooling from 60 to 20°C;
- 4 hour maintenance at 20°C.

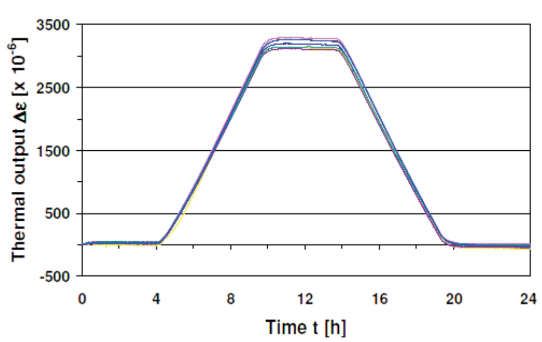
Previous tests showed that maintenance periods of 4 hours assure uniformity of temperature on the samples and between samples and air into the climatic chamber. Besides, heating or cooling with $\Delta T = \pm 40$°C in 6 hours allow to repeat thermal variations reproducing the same conditions without hysteresis cycles, that is to say without residual deformations. Experimental data were employed to estimate the thermal expansion coefficients and the corresponding actual-deformations of the samples without grid influence. The obtained results represent average performances of the specimens at uniform temperature, as the thermal conditions can be controlled into the climatic chamber, but exclude the influence of other important factors, first of all the absorption coefficient for solar radiation of the different materials. After the calculation of thermal expansion coefficients from (5), the deformations induced on photovoltaic modules surface were determined. In an elastic body, a temperature variation ΔT produces a thermal deformation εS, $_{\Delta T}$ defined by

$$\varepsilon_{S,\Delta T} = \alpha_S \times \Delta T$$

The thermal deformations were calculated for each sample on the basis of the strain gauge measurements. Finally, thanks to samples symmetry and strain gauges arrangement, maps of thermal expansion state on the specimen's front side for working temperatures were drawn.

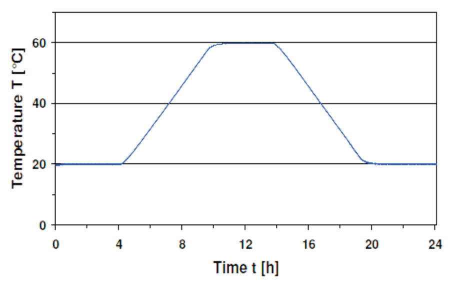
The photovoltaic panels were subjected at least to three thermal cycles into the climatic chamber and similar performances were observed for each one. In Figure 14 an example of deformation trend in the eight points selected on *PV1* sample is given: figure shows measured thermal output Δε vs. time *t*, during a 24 hours thermal cycle.

Figure 14: Thermal Output Δε vs. Time *t* during a 24 Hour Thermal Cycle on *PV1* Sample



The corresponding surface temperature T vs. time t is drawn in Figure 15 data were measured on PV1 sample during the same cycle and are averaged values of the thermal conditions in the different points on specimen front side; the thermo-hygrometric parameters are in fact rigorously controlled into the climatic chamber

Figure 15: Surface Temperatures *T* vs. Time *t* during a 24 hour Thermal Cycle on *PV1* Sample



In Particular, About the Deformation Surface Trend

- Sample PV1: surface has a higher thermal expansion coefficient than other samples and it is characterized by minimum deformation values on the central cells.
- Sample PV2: deformation state is very peculiar; map shows that thermal expansion coefficient has absolute maximum value on the panel centre and relative maximum values near the longer sides, but far from the corners.
- Other samples, PV3 and PV4, are characterized by very similar performances. They have similar materials and geometric characteristics of PV2, but mono-crystalline instead of poly-crystalline silicon; maps show that low and medium deformation values are present on central zone and maximum values near the corners of the panels; in particular, PV3 has minimum deformation values where there aren't photovoltaic cells.

CONCLUSION

Photovoltaic panels are subjected to thermal stress due to solar radiation, variable on different points of the module, which produces a particular deformation state. Thermal expansion may have negative consequences for the cells, according to materials assembling. Evaluation of deformations induced by thermal stress on the panel front side, directly exposed to the sun in working conditions, was carried out with strain gauges measurements in climatic chamber. Measurements were carried out by means of electric circuits, according to ½ Wheatstone bridge model.

Measurements showed that thermal deformations on photovoltaic panels surface were not critical. Such a performance could be due to uniform conditions of temperature into the climatic chamber. The methodology developed is allowed to evaluate the most critical conditions and to avoid possible structural damages on photovoltaic cells. The methodology of deformation measurements can be applied to different kind of materials, employed in many fields of modern buildings.

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