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Stress and Vibration Analysis of Microsatellite Structure

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Abstract**—** *Interest in small satellites is growing fast world-wide. Businesses, governments, universities and other organizations around the world are starting their own small satellite programs Sudan has extended boundaries and huge resources never profiteered from this technology so the main objective is to manage and control these resources using satellite technology.*

Microsatellite (50 kg) was modelled and subjected to static test aiming obtain the stresses and the deformations then it followed by dynamic test which contain modal test and random vibration. All tests performed using ANSYS program, on static analysis component weight regarded as loads in the ground environment, model was fixed on the bottom tray. Stresses and deformation obtained with maximum values of 33.153 MP on rack hole and 0.388 mm on the mid of third tray respectively. Modal test results are the first six mode shape and the natural frequencies which lay on the range of 112 Hz to 302 Hz which are acceptable with PSLV launcher.

Keywords**—** *Microsatellite, modal test, Random vibration, PSLV launcher.*

I. INTRODUCTION

Space research is one of the most developed science in the world which gone far away now, the important information which we can gain from satellite in each two main aspects (civil & military) deserve the space huge invests, Interest in small satellites is growing fast world-wide. Businesses, governments, universities and other organizations around the world are starting their own small satellite programs [Boudjemai et al., 2005]. Aerospace is one of the most developed science all over the world and it is not exclusive to the developed countries. There are many developing countries access to this field. In a country like Sudan with extended boundaries, huge internal resources never profiteered. Also, there are numerous security problems represent some challenges for the government. It is easy to manage, control and solve this types of problem using satellite technologies that used worldwide. Satellite Structure subsystem used to transmit loads, provide surfaces for mounting functional hardware and protect the internal component, it provides support for all load environments from prelaunch through launch and includes on-orbit loads. Therefore, designing the structure and analysis to obtain good performance and operation for satellite structure is a main challenge. The structure success means must survive in all environments without detrimental deformation. In this context the main objectives of this research are to design a structure for microsatellite, Static analysis for the structure to obtain maximum stresses and deformation which structure can sustained, Modal analysis for the satellite structure to obtain the natural frequencies and mode shapes. And Random vibration analysis satellites are used mainly for communications, such as beaming TV signals and phone calls around the world. A group of more than 20 satellites make up the Global Positioning System, or GPS. If you have a GPS receiver, these satellites can help figure out your exact location. A spacecraft orbiting the earth, another planet in our solar system or even beyond that, is a part of a complex infrastructure consisting of the launch vehicle, which positions the spacecraft in a certain orbit and ground based stations that cater for the communications. [Wijker, 2008].

II. MATERIALS AND METHODS

To design the microsatellite, the first step is to decide for what reason we need the satellite which will affect in selecting the internal component and its weight. CAD package will be used to conduct the step and precisely SOLIDWORKS will be used. The suggest material for microsatellite structure is aluminum 6061 T6 which is the most commonly used metallic materials in spacecraft due to its performance characteristics, cost and advantages of high strength to weight ratios, high ductility, ease of machining [Abdelal et al, 2013]. For modelling the structure tray with dimensions 400mm * 400 mm and 4 mm thickness made by aluminum sheet will be used to carry subsystems. Model contains four trays to carry each subsystem component. Satellite top head contain holes for camera and supporting structure to hold and fix the payload body. There are two ways to keep the gaps between trays either use pad with specific height or use angle brackets which fix with the satellite corners and trays. The bottom tray contains the satellite launcher interface. Polar Satellite Launch Vehicle offer different interface depending on the satellite configuration and mass which published in launcher manual. The rocket will be chosen for launching the satellite is Polar Satellite Launch Vehicle which belong to the Indian Space Research Organization (ISRO) [P S L V User's Manual,1999], the rocket parameter will affect the configuration of the bottom tray and the different external loads such as random vibration, acoustic loads, the criteria of acceptance the natural frequencies. The interface specification affords in the rocket manual and categorize with Auxiliary Satellites interface.

A. CAD Model

Micro- satellite design using Solid Work the shape obtained after number of iterations from similar micro-satellite structure. The internal components of this satellite have been simplified to reduce modal analysis running time. Figure 1 shows the micro-satellite model's loads and constrains, two models with different thickness of (2mm & 4 mm) were studied at this project.

The model consists of three trays and pads for adjusting the height between each tray and bar for tightening model's component. The upper case contains the payload and the lower tray contains the interface between the satellite and the launcher and also hold the batteries the second tray contains the communication and the GPS the third tray hold the ADCS system.

The model has been meshed using tetrahedrons with number of 42000 elements. The load applied represent the components weight detailed in table 1. The mass and weight for each component represented by blocks, the arrows show the direction of loads from D to G in figure 1. The model constrains are displacement 1 supports and cylindrical supports (A, B and C) in figure on bottom tray and the top of bars.

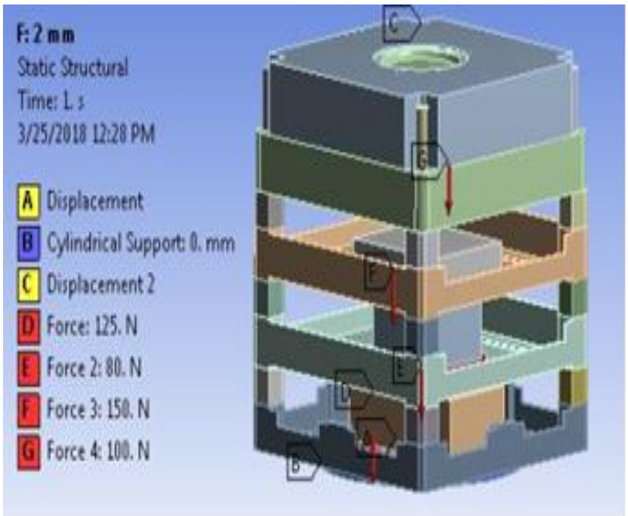

Fig. 1. Micro-satellite Structure

TABLE 1. Component Weight

Component	Weight (Kg)
Batteries	12.5
Communication + GBS	8.0
ADCS	15.0
Payload + antenna	10.0

III. RESULTS AND DISCUSSION

A. Static Analysis

Static stress was performed to obtain the stresses and the deformations for the agreed model and the Figure 2a down shows the contour of Von Mises stresses distribution with maximum and minimum stress of 33.153 MPa and $0.167x10^{-3}$ MPa respectively.

Figure 2b shows close view to tray number three where maximum stress occurred. It shows that the maximum stress occurred near to the rack hole the area of higher stress concentration.

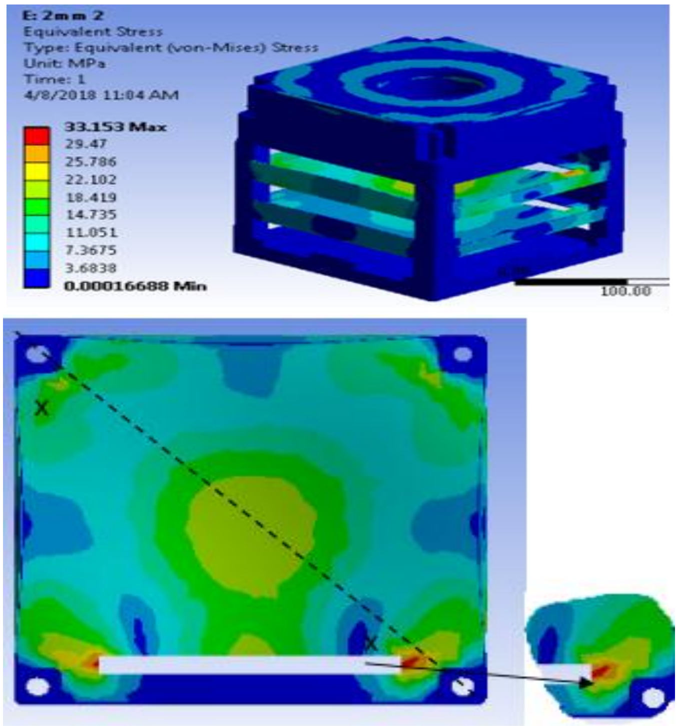

Fig. 2. (a,b) Von Mises stresses distribution in tray No. 3

Figure 3 shows the distribution of the stress along the line X-X. It illustrates three peak points two close to support area and the third one on the middle which expose to the load. The maximum stress occurred near to the rack hole the area of higher stress concentration.

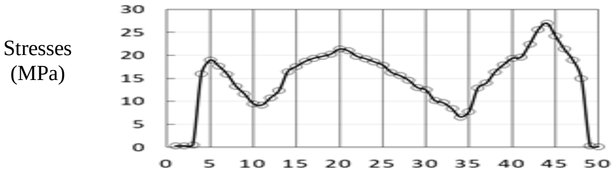

Fig. 3. The stress distribution along the line X-X

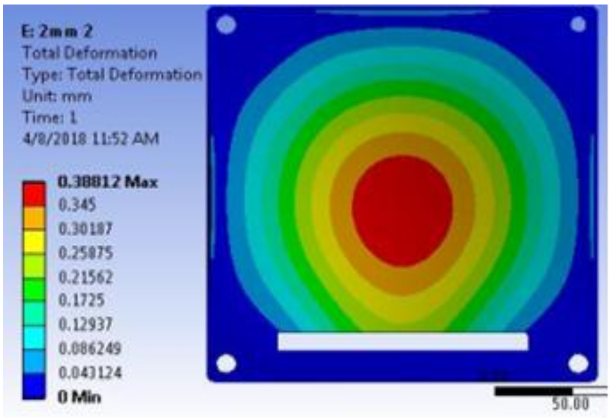

Fig. 4. Micro satellite deformations

Figure 4 shows deformation contour for micro satellite model. Results shows that maximum deformation of 0.388mm occurred at the middle of tray number three which carried the weight of ADCS. Since the tray was fixed at the corner and carried the load at center it is reasonable to obtain maximum deformation at that area. This deformation can be limited when we have sensible component closed to that position tray.

Table 2 shows different stresses contour (Von Mises stresses, maximum principle and shear stress). The increased of stresses is noticed as a result of change in thickness, where smaller thickness experienced higher stress of 33.15 MPa. It is also noticed increasing of the total deformation (0.25 mm) at the thinner thickness.

TABLE 2. Static Stresses

Thickness (mm)	**Von Mises (MPa)**	**Principle Stress (MPa)**	**Shear Stress (MPa)**	**Total Deformation (mm)**
2	33.153	35.07	7.33	0.2547
4	10.008	9.059	2.3988	0.0527

B. Model Analysis

Modal test was performed for the micro-satellite structure with thickness of 2 mm to obtain the natural frequencies and mode shapes of the structure. When frequencies of loading vibrations match one of these natural frequencies, resonance takes place and that what we avoided. The mode shape performed for two cases free constrain and fixed/ free constrain

Results shows that the first six frequencies obtained on the range of 112 Hz to 302 Hz. This values are acceptable since it is within the range of the launcher requirements. The maximum frequency value occurred at the sixth mode which is 301.82 Hz. The mode shape is torsion around horizontal axis with 21.757 mm deformation.

C. Random Vibration Analysis

Random vibration analysis enables one to determine the response of structures to vibration loads. Power spectral densities (PSD) in G2/Hz are used to characterize random vibration signals while G is the launcher acceleration and Hz represent the frequency of the vibration loads during all launching phases. The loads for this analysis obtained from the launcher requirements which was used in the three axis. Figure 4.15 shows the maximum Von Mises value in Y axis of 11.6 MPa occurred at the second on tray rack hole. The result is compared with Anselm picosatellite research results who applied the same load for 10 cubic centimeters and the Von Mises result obtained is 33 MPa [Anselm, 2016].

IV. CONCLUSION

Micro- satellite designed with dimension: 250mm x250mm and 267mm height in two different thickness which are 2 mm & 4 mm. consists of three trays and pads for adjusting the height between each tray and rod for tightening model’s component. The upper case contains the payload and the lower tray contains batteries and the interface between the satellite and the launcher the second tray contains the communication and the GPS the third tray hold the ADCS system. The internal components of this satellite have been simplified to reduce modal analysis run time. Static stress was performed at microsatellite structure to obtain the stresses and the deformations.

Results shows maximum stress of 33.175 MPa at occurred near to the rack hole the area of higher stress concentration and maximum deformation of 0.388 mm at the middle of tray number three which carried the weight of ADCS. Modal tests analysis was performed in two cases. Free-free constrain to obtain the natural frequencies for the structure and fixed-free constrain which stimulate the launching phase for the satellite. Test performed to get the first six mode shapes and natural frequencies and the result obtained are frequencies on the range of 112 Hz to 302 Hz and that are acceptable with launcher requirements.

Random vibration test was performed to know the impact of loads on instruments and equipment box. The input data were taken from launcher sheet and the results obtained were 15.177 MPa and 0.124 mm for Von Mises stress and deformation respectively occurred on the head case for stress and third tray for deformation.

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REFERENCES

[1] Boudjemai, A.; Bekhti, M.; Bouanane, M. H.; Mohammed, A. M. Si; Cooper, G.; Richardson, G. Small satellite computer-aided design and manufacturing Proceedings of the European Conference on Spacecraft Structures, Materials and Mechanical Testing 2005 (ESA SP-581). 10-12 May 2005, Noordwijk, The Netherlands. Edited by Karen Fletcher. Published on CD-Rom, id.#36.12005

[2] Wijker, J. (2008). Spacecraft structures. Berlin: Springer first edition.

[3] Anselm Chukwuemeka Okolie, Spencer O. Onuh, Yusuf T. Olatunbosun, Matthew S. Abolarin. Design Optimization of Pico-satellite Frame for Computational Analysis and Simulation. American Journal of Mechanical and Industrial Engineering. Vol. 1, No. 3, 2016, pp. 74-84. doi: 10.11648/j.ajmie.20160103.17

[4] Abdelal, G., Abuelfoutouh, N. and Gad, A. (2013). Finite element analysis for satellite structures. London: Springer.

[5] S Ramakrishnan Polar Satellite Launch Vehicle Auxiliary Satellite User’s Manual Doc No: VSSC: PSLV:PR:PM:176/99 Issue – 1 December 1999.