AN ANALYSIS AND DESIGN OF THE MECHANISMS USED TO DEPLOY SOLAR ARRAYS ABOARD A SMALL SATELLITE USING LATEST TECHNOLOGY

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Article History: Received: 03.03.2023 **Revised:** 14.04.2023 **Accepted:** 09.06.2023

Abstract:

This study provides an analytical simulation of drag braking experienced by a miniature spacecraft while its solar array system is deployed in orbit. The study was carried out by the authors of the current work. This offers the designer aid in detecting possible difficulties that may develop when the system is being tested on the ground. A piece of software known as Mechanical Desktop (MDT) is used in order to model the deployment mechanism (DM), and another piece of software known as the Finite Element Analysis Package is utilized in order to analyse the DM (ANSYS 11). The Design and Stress analysis is carried out at the periods of the DM's operation that are considered to be the most crucial. In order to establish whether or not the DM can be relied upon, several various models of finite element analysis were investigated. Testing for random vibration, testing for modal vibration, and testing for static vibration were all tied to these studies in some way. The current investigation will ensure that the mechanism will continue to function properly even after the satellite has been launched into orbit, and it may be able to assist in the evaluation of whether or not the mechanism will be able to persist under operational situations that are typical of the real world.

Keywords: Satellite, Deployment Mechanism, Solar Array, Finite Element, Modal Analysis

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DOI: 10.31838/ecb/2023.12.s3.467

1. INTRODUCTION

The engineering design of today has to strike a compromise between opposing objectives in order to improve performance while also reducing development costs and time frames. In this instance, solar power was used since it is a kind of sustainable energy that is also capable of powering relatively small spacecraft. It is necessary to place a significant number of solar panels on the surface of the satellite in order to produce sufficient amounts of power for the reliable functioning of the payload as well as the computer and communication systems that are housed on the satellite. (2023) Innovative solutions, such as solar panels that could be folded down to take up less space onboard the launch vehicle, were created. During the time that immediately after orbital insertion, which was known as the unfolding phase, self-actuated deployment mechanisms used the energy that was stored in a torsion spring to energize the solar arrays. This phase occurred after the orbital insertion phase. When faced with such conditions, the use of drag braking is a strategy that may be utilized to lessen the severity of shock loading or eliminate it completely. The perfect drag brake would be small and lightweight while also being capable of absorbing and dissipating a sufficient amount of energy to provide smooth deployment and motion without any unexpected loadings or reactions at the end of the stroke. This would be the ultimate drag brake. The braking system is shown below in a simplified isometric perspective. It consists of a small drum that has been specifically designed for use as a brake, as well as frictional shoes that are compressed by a spring and forced into contact with the drum. (Dida, 2019)

Objective

The research aimed to fulfill the following objectives:

- To study the Detailed Description of the Structure and Model
- To study An Investigation into the Statics
- The Random Analysis in Addition to the Modal Analysis of DM

2. METHODOLOGY

It is estimated that the brake will weigh 0.350 kilograms and that If we assume a reasonable coefficient of friction of 0.5 in a regular atmosphere and 1.0 in a microgravity environment during an altitude of 768 kilometres, it will be possible to deploy the solar arrays in some kind of a time range of 2 to 3 seconds. Strict testing is required before a working prototype of the intended brake can indeed be made accessible. First, a DM model is built with the help of Mechanical Desktop (MDT), and then it is analysed with the help of Finite Element Analysis Package (FEAP) (ANSYS 11). Static, modal, combined random vibration analyses were used in a simulation to describe the dynamic behaviour of the machine structure and even to estimate its resonant frequency and structural response to the most extreme scenario of Launch Vehicle (LV) loads. This allowed for the estimation of the dynamic behavior of the mechanical structure. When a mechanical structure is allowed to resonate, even relatively minor pressures may cause the structure to deform noticeably, which can put it at risk of being damaged. The fundamental cause of resonant vibration is the dynamic interaction that occurs between the inertial and elastic deformations of the materials contained inside a structure. To have a full comprehension of the structural vibration difficulties, it is necessary to ascertain the structure's resonance frequencies. Modal analysis refers to the process of examining vibration modes, and it is often used in order to identify the vibrational modes of mechanical systems.

Detailed Description Of The Structure And Model

Two foldable deployable solar array units (DSAs) that each measure around 721 cm in length and 130 cm in width when deployed and provide 630 watts (initial) of electrical power make up the solar array for CTS. the configuration of the various components that make up a DSA. These components consist of a flexible blanket (on which the are attached solar cells as well as correlating bus wiring)*, a single BISTEM carbon steel book, an inboard pallet, an outboard pressure plate, and then a corresponding substructure. In addition, these components are attached to a corresponding substructure. The spacecraft's internal components include a deployment actuator, a slip ring assembly, and a drive and track system for keeping the DSA in a solar-normal orientation. The outward-facing part of a DSA is lightweight and mechanically malleable, weighing in at about 19 kg. The base of the blanket is a bonded composite fabric of Kapton and glass fibre measuring 76 m in thickness. The fiberglass side of the substrate is bonded with solar cells, cover glasses, with adhesives for a total thickness of 440 m. The borders and the blanket's centerline have flexible bus lines for electrical power and instrumentation. These bus lines are attached to the inboard end of the spacecraft by means of a diode board and a flexible connector cable, which are then connected to the spacecraft's electrical subsystem by means of a slip ring assembly. As can be seen in the diagram, the blanket is supported structurally by a deployable BISTEM of 3.40 cm diameter that is set back from the blanket by about 6.3 cm. Blanket ends are supported by the inboard pallet and the outboard pressure plate. For further safety during takeoff, the blanket might be sandwiched between the pallet and the plate. In the beginning of the expedition, the blankets are spread out in a concertina formation . A constant force spring system at the boom's aft end keeps the blanket taut at its standard tension of 35.6 N. Each blanket's edge is reinforced with a thin stainless steel line that is tensioned to a constant force of 1.3 N. Using a drive and track system powered by a stepper motor, the outboard components may rotate with respect to the spaceship. Every day, the DSA completes one rotation. More so, the option to spin at a speed of 35.7°/min is available. (Patki et al., 2020)

Therefore, the latter scenario is preferable to use if you want to reduce the number of truncations and rounding mistakes. The DM brake assembly's mesh design can be seen here. 2.2. Component Materials The components' particular needs guide the selection of the materials to be used in their construction. For the various pieces, including the spinning shaft, the screws, and the joints, structural steel was used. Brake shoes may also be made from grey cast iron. The drums were constructed using AISI 4130 steel sheets and 304 stainless steel plates. Guide bushings were made from a commercially available aluminium alloy, while the moveable bracket, housing cage, as well as friction arms were all constructed from aluminium alloy AMG6. Elements of springs were made from piano wire springs that conformed to DIN 17223D.

The DM is constructed with the assistance of the MDT-programmed Mechanical Desktop, and then the results are evaluated only with help of something like the Finite Element Evaluation Package (ANSYS 11). Static, modal, and random vibration analyses were carried out in addition to the random vibration analysis in order to simulate this same dynamic behaviour of both the mechanisms configuration and to approximate its resonant frequency but instead structural response in the supposition of Launch Vehicle (LV) loads representing the worst-case scenario. This was done in order to facilitate the description of the dynamic behaviour shown by the structure of the mechanism.

A mechanical structure may resonance, which is a phenomenon in which relatively little forces can result in severe deformation; as a consequence, the structure may sustain damage. The primary contributor to resonant vibration is an interaction between the inertial and elastic deformations that occur inside a structure's constituent components. (2023) It is necessary to locate the structure's resonance frequencies in order to get a deeper level of comprehension about structural vibration issues. Modal analysis is a well-known method for locating the many modes of vibration that may be produced by machines and systems. (Muhammed et al., 2022)

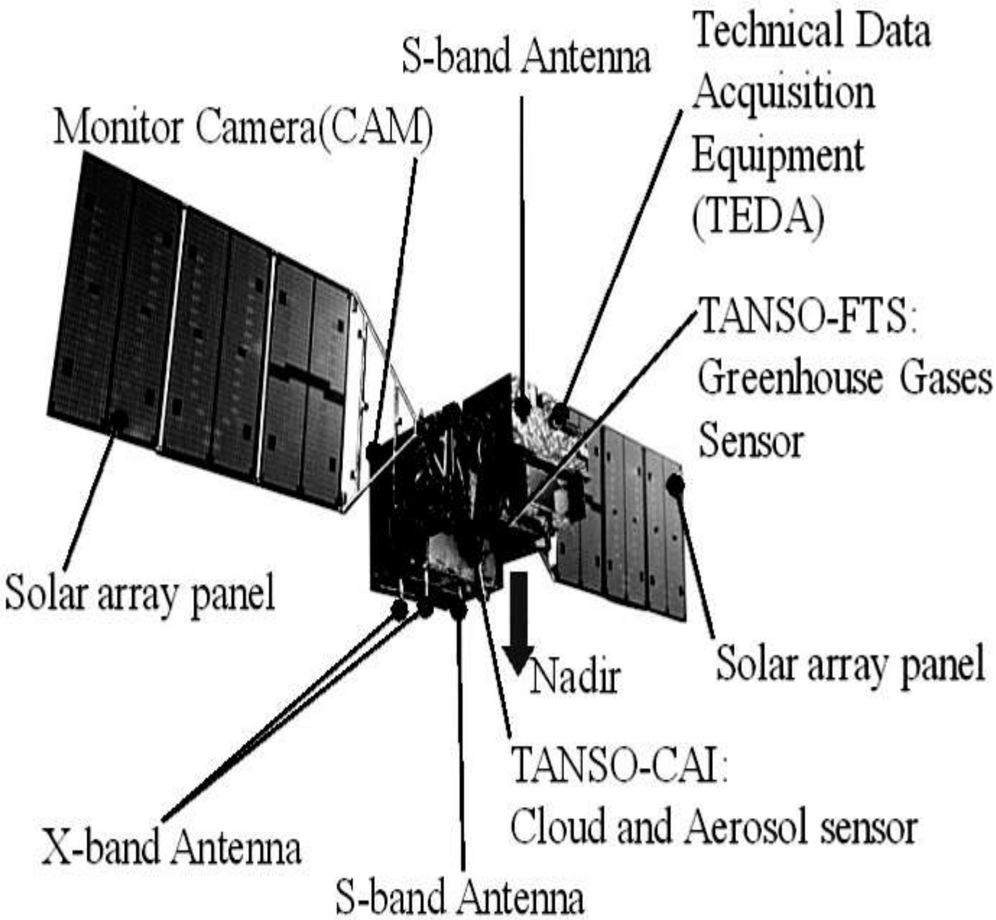

Figure 1. Satellite solar array

An Investigation Into The Statics

When parts of a mechanism are exposed to static loading, the objective is to characterize the resulting load distribution, strains and stresses throughout the structure of those parts. This is done by measuring how the load is distributed over the structure of the component. When conducting out static analysis under load, forces and moments of a static character are exerted onto the components that make up the assembly of the mechanism. These forces and moments are then analyzed to see how they affect the mechanism. The linear static analysis in ANSYS is what's used to do the heavy lifting when it comes to calculating stresses, strains, and deformations. the ANSYS static analysis begins with the definition of the geometry, continuing through the definition of the connections, meshing the model, and going all the way up to the post-processing of the results about the static structure. In addition to this, it illustrates the critical places on the movable bracket in which the greatest deformation takes place, with the highest computed value coming in at 2,2501e-004 meters. According to the results, the deformations, strains, and stresses that were detected did not in any way jeopardize the structural integrity of SA as well as the movable bracket. (2023) This was the conclusion reached after analyzing the data. the critical sections that are experiencing the greatest amount of strain in the DM, and it also depicts the locations of applied loads as well as the fixed nodal points that seem to be fixed supports. According to the findings of the study, the zone of the DM that exhibits the highest critical strain also referred to as the zone that is under the most pressure, can be found on housing cage 2,1718e-002m/m. The size of the stress that occurs on the cubic joint is determined to be 2,7544e+008 Pa, and the outcomes of the research indicate that this stress is the most important one that occurs. The design was structurally sound even when it was exposed to static loading conditions since the maximum shear stresses that were calculated were not even close to being equal to the shear strength of the component. (Pelton & Madry, 2020)

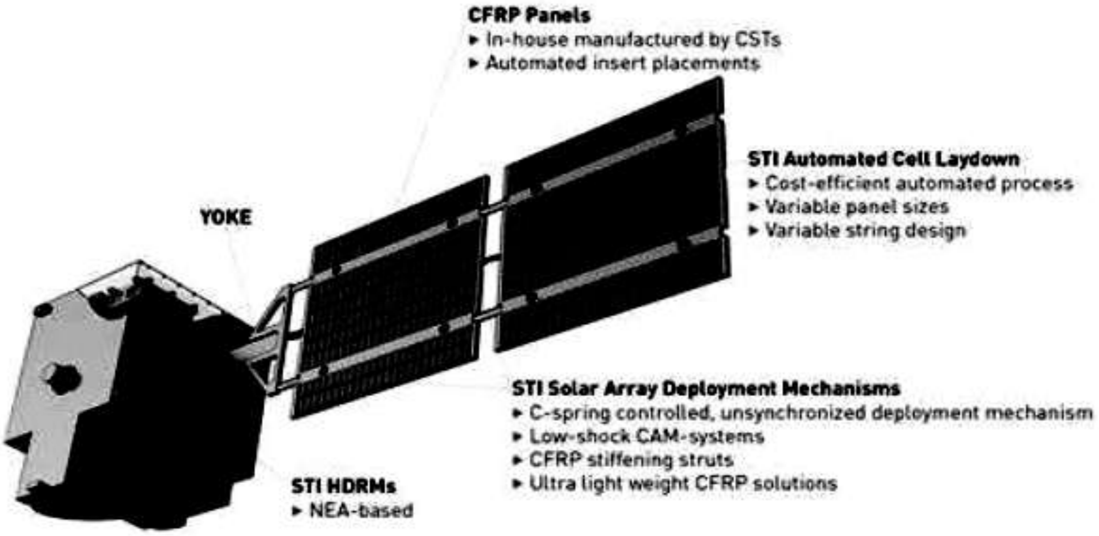

Figure 2. Solar Array

The Random Analysis In Addition To The Modal Analysis Of DM

Modal Analysis of Discrete-Event Simulation It is possible to determine the modes of vibration and indeed the associated natural frequencies by conducting modal analysis and testing. In addition, these methods may be used to gather the structural matrices necessary for the assembly's dynamic analysis. Because it was properly collected from a credible test, the fundamental structural dynamic data provides an accurate identification of something like the structural behaviour at the modalities of interest. The contributions of both the mass, stiffness, as well as damping characteristics somewhere at modes of interest provide the basis for these predicted matrices, which account for the real boundary conditions. These measurements are then used to refine the structure's finite element model and find solutions to the following problems or ways to improve the mechanism's dynamic responsiveness. (2023) In order to solve for the first five parameters that are represented in the DM model, modal analysis was carried out using the ANSYS 11 software. Give me a good illustration of the first two types of vibration that occur from this. This study is also utilized to gain insight into how DM acts and reacts to its environment, which, of course, helps with the subsequent laboratory analysis Prior to testing, a preliminary estimate of such DM Eigen frequencies and mode shapes may be obtained by analysing the normal modes produced by the FEA for the DM model. The excitation settings, shaker positions, and accelerometer installations have all been planned using this information. (Li et al., 2017)

Random-Sample Analysis Understanding the basics of random vibration is essential for designing, developing, and creating lightweight, cost-effective mechanisms that can operate reliably under a wide range of situations. Then and only then can such mechanisms be designed, developed, and created effectively. Mathematically, random vibration may be analyzed as a set of overlapping sinusoidal curves, distinguishing it from periodic vibration on the basis of its lack of periodicity. All the frequencies within a particular bandwidth are stimulated simultaneously in this setting. (2023) The Power Spectral Density (PSD) curve is one of several possible types of curves that may be used to represent the needs for the random vibration input. Statistics from the PSD. The frequency (in Hz) and combined power spectral density (in G2/Hz) are represented on a log-log scale, exhibiting frequency anywhere along horizontal abscissa and spectral density along the vertical ordinate. Take into consideration that acceleration, denoted by the sign RMS for root mean square, is calculated as the region lying just under the random vibration curve. These are two really important points to remember. the DM-model-compatible curved input from random vibration. Based on the DM analysis, the stresses may be linked to their occurrence, and thus the values of either the load transfer were determined to have happened at an exponential function of 1 sigma, with a probability of around 68.3% along the X-axis. That both torsion spring and the compression springs are shown to be most significantly impacted at a frequency of 733.18Pa. Since both springs have the same values, this is proven. Because these stresses are so much lower than the structural failure limits, DM is completely safe to use, and it seems that it will continue to absorb vibration loads for quite some time after the spacecraft has been launched into orbit.

Frequency-dependent deformations occurred in all three axes (X, Y, and Z), although deformations caused by velocity, as well as acceleration loads, posed no danger to the DM elements. Frequency-dependent loads caused deformations in all spatial dimensions (X, Y, and Z). (Kamboj et al., 2023)

3. CONCLUSION

After computing the displacement and deformation after the completion of a linear static analysis of the DM utilising FE analysis in ANSYS, the study was considered complete. We have accomplished the modal analysis, and the first five resonance frequencies have been determined (or mode shapes). During the random vibration test, it was discovered that the torsion combined compression springs had a total strain of 733.18Pa, which was considered to be their greatest strain. The findings of the FE study indicated that the simulation of the DM for SA of a spacecraft would be able to withstand the vibration stresses, moments, but instead forces that would be present throughout the entirety of operation in conditions that would be comparable to those that would be anticipated after the satellite was launched into orbit. The findings of this study indicate that the miniature shoe brake that was developed may be used to control the unfolding of the solar panels, protecting them from shock loads and also injury after the deployment process has been completed.

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