Design analysis of solar panel structure LAPAN-Constellation Satellite using finite element method

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Abstract. Satellite Technology Center (Pusteksat) of LAPAN currently develops a satellite constellation with communication mission. This satellite will implement a deployable solar array to perform its missions. The objective of this research is to find solar panel structure with natural frequency in accordance with the requirements of the launcher and have the minimum mass. This method starts by determining the requirement of solar panel structure and then designing the solar panel into three models as follow: solar panel structure with solid aluminium sheet model, isogrid and orthogrid model, and honeycomb model. The material used for solar panel structure for aluminium sheet and isogrid and orthogrid model is Al 7075-T6 because the material is light in weight and has a high stiffness to withstand loading conditions. Meanwhile, for solar panel structure honeycomb use aluminium alloy 5052 for both face and core follow the previous satellite. The next step is analyzing the natural frequency of three models solar panel structure with modal analysis. This study shows that solar panel with honeycomb model give the best option as a solar panel structure on a constellation satellite. From the result, it can also predict the modal shapes that can be used as a place to lay the accelerometer when testing and measuring natural frequency on vibration test machines.

1. Introduction

Satellite Technology Center (Pusteksat) of LAPAN that has heritage and experience to develop small satellite [1][2][3] currently proposed design of satellite constellation with communication mission in equatorial countries including Indonesia. This satellite will orbit in equatorial Low Earth Orbit at an altitude of ± 600 km and a 0° inclination angle. This satellite will carries several communication payloads as follow: VHF Data Exchange System (VDES), Voice Repeater (VR), Automatic Packet Reporting System (APRS), Automatic Identification System (AIS) and Automatic Dependent Surveillance-Broadcast (ADSB).

The power requirement for a satellite depending on the mission. The more missions the satellite carriers, the more power it will need, thus requiring a larger solar array but there will be increased in dimension. However, due to the limitation of the dimensions of the launcher rocket, the solar array must be folded or stowed during launch, which will then be deployed when the satellite is separated from the launch vehicles and has reached the predetermined orbit. Moreover, based on research on satellites in equatorial orbit, solar panels with simple deployments produce double percentage of illumination compared to solar panels with body mounted[4]. Therefore, this satellite constellation will implement the deployable solar array to perform its missions as illustrated in figure 1.
The main structure of deployable solar panel usually made by aluminium alloy sheet [5] and aluminium honeycomb plate [6][7]. Aluminium alloy used in spacecraft construction because of durability, resistance to various types of corrosion and light in weight and have good thermal stability. Meanwhile, the aluminium honeycomb plate is a sandwich structure that consists of upper face and lower face of thin sheets and aluminium honeycomb structure in the middle as a core [8]. Some of the unique characteristic which make honeycomb structure a choice for this application are due to low surface density, high specific stiffness and good fatigue resistance [9]. Therefore, in this study, there will be a comparison of solar panel structure made of aluminium sheet with aluminium honeycomb in solar panel deployable structure.

In satellite launches, the point to consider is the natural frequency of the system or structure. The value of the natural frequency structure should not be the same or adjacent to the natural frequency of the launcher. Therefore, the structure including solar panel structure will not resonate and will not have deformation or failure. Modal analysis by using finite element method has become a widely useful to get this natural frequency and can be used as tools to select the solar panel structure. Moreover, another point to consider is the mass of the solar panel structure. Total mass of spacecraft structure is one of critical design factors due to the limitations inherent in the payload capabilities of launch and orbital transfer vehicles as well as for reduced launch costs [10][11]. Therefore the objective of this research is to find solar panel structure with natural frequency in accordance with the requirements of the launcher and have the minimum mass.

2. Materialas and methods

2.1. Determining the requirement of solar panel structure

One of the launchers that meets the mission requirements of a communications satellite is LauncherOne. This launcher requires a minimum natural frequency of 35 Hz and maximum payload mass of 500kg [12]. Thus the solar panel structure must satisfy these requirements. Mass of 500kg is for the total mass of the satellite including payload, structure and all of supporting component. Therefore, to fulfil the requirement, the selected solar panel must have the lightest mass.

2.2. Designing the solar panel structure

Solar panel structure is designed based on the size of the solar panel used where the size is 700x350mm as illustrated in figure 2. In this study, solar panel structure is designed in three models as follow: solar panel structure with solid aluminium sheet model, isogrid and orthogrid model, and honeycomb model. Solar panel structure with solid aluminium sheet model was designed with a thickness of 6mm and 8 mm to determine the effect of thickness of solid aluminium on natural frequency. As for reducing mass, solar panels are designed with isogrid and orthogrid models at 10mm thickness. Orthogrid model is rectangular cut-out where the pattern is square which aims to maximize...
strength to weight ratio. This model is the best option for fabrication on milling machine [13]. Meanwhile isogrid model is a pattern of equilateral triangles that machined from flat surface. This model has advantages such as high stiffness, light in weight and thermal stability [14]. Orthogrid and Isogrid model can be seen in figure 3. The next design is the design of solar panel structure using aluminium honeycomb. The thickness of the honeycomb used is 8mm for the core and 1 mm for each face. So the total thickness of this solar panel structure is 10mm.

![Figure 2. Dimension of solar panel](image)

![Figure 3. (a) Orthogrid and (b) Isogrid Models](image)

2.3. Collecting/establishing the material of solar panel structure

The spacecraft industries have long relied upon aluminium alloys. The material used for solar panel structure for aluminium sheet and isogrid and orthogrid model is Al 7075-T6 because the material is light in weight and has high stiffness to withstand loading conditions [16]. The properties of this material can be seen in table 1. Meanwhile, for solar panel structure honeycomb use aluminium alloy 5052 for both face and core follow the previous satellite [17]. This property can be seen in table 2 for the face and table 3 for core properties.

| Table 1. Properties of Aluminium Alloy Al 7075 |
|-----------------------------------------------|
| Item                                          | Unit |
| Density                                       | 2810  |
| Poisson Ratio                                 | 0.33  |
| Modulus Elasticy                              | 71.7  |
| Shear Modulus                                 | 26.9  |
### Table 2. Properties of Aluminium Alloy Al 5052

| Item              | Unit   |
|-------------------|--------|
| Density           | 2680 kg/m³ |
| Poisson Ratio     | 0.33 |
| Modulus Elasticity| 70.3 GPa |
| Shear Modulus     | 25.9 GPa |

### Table 3. Properties of Aluminium Alloy Al 5052

| Item              | Unit   |
|-------------------|--------|
| Density           | 97.7 kg/m³ |
| Poisson Ratio 12  | 0.30 |
| Poisson Ratio 12  | 0.30 |
| Poisson Ratio 12  | 0.30 |
| Modulus Elasticity| 0.67 GPa |
| Modulus Elasticity| 0.283 GPa |
| Modulus Elasticity| 0.1655 GPa |
| Cell Size         | 1/8 Inch |

2.4. Analyzing the natural frequency of solar panel structure

Finite Element analysis of the design has been established using MSC. Patran and the element employed in all of the models (design) are quad-4 element topology (four corner nodes). In modal analysis, the detail like holes and pores can be ignored, because the natural frequency of a structure is mainly decided by stiffness and structural mass. The boundary condition in the modal analysis concern in 3 place, two place is the location for hinge to structure satellite which is constrained in displacement of x, y and z are zero, and rotation of x, y, and z are zero and the remaining place is the location for hold mechanism which is constrained in displacement of x, y and z are zero.

In this research, honeycomb model use equivalent plate methods which replace the honeycomb model into an equivalent single plate [17]. This method has the objective of creating simplified finite element model with less numbers of elements, less number of material types and therefore more efficient. To estimate the equivalent parameter of honeycomb equivalent models can be seen in equation (1), (2), and (3) [18].

\[
t_{eq} = \sqrt{\frac{3h_c^2 + 6h_c + 4t}{f}}
\]

\[
E_{eq} = \frac{2t}{t_{eq}} \cdot E
\]
\[ G_{eq} = \frac{2t_f}{t_{eq}} \cdot G_f \]  

(3)

Where,
- \( t_{eq} \) = equivalent plate thickness
- \( h_c \) = core thickness
- \( t_f \) = face thickness
- \( E_{eq} \) = equivalent plate Young Modulus
- \( G_{eq} \) = equivalent plate Shear Modulus
- \( E_f \) = Modulus young face
- \( G_f \) = Modulus shear face

From the equation is derived the value of parameter of honeycomb equivalent models as seen in table 4.

| Item                              | Unit   |
|-----------------------------------|--------|
| Equivalent plate density          | 393.19 Kg/m3 |
| Poisson Ratio                     | 0.33   |
| Equivalent plate Young modulus    | 9 GPa  |
| Equivalent plate thickness        | 0.01562 mm |

3. Results and discussion
The coloured fringe gives the amplitude of the displacement vector describing the shape each mode. The blue colour corresponds for null displacement and the red one presents the maximum amplitude.

3.1. Effect of thickness on aluminium sheet model
The influence of the sheet thickness on the natural frequency is considered in this sub-section. The thickness of the skins is used as follows: 6mm and 8mm. Figure 4. shows the mode shape of the modal analysis and table 5 is the natural frequency. According to the results obtained, we note that sheet thickness of the aluminium sheet affects the natural frequency but not the mode shape. The thicker the aluminium sheet, the resulting of natural frequency also increase, but with consequences on the increased weight as can be seen in table 6.

| Solar Panel Solid 6mm (Hz) | Solar Panel Solid 8mm (Hz) | Solar Panel Isogrid 10 mm (Hz) | Solar Panel Orthogrid 10 mm (Hz) | Solar Panel Honeycomb (Equivalent Method) (Hz) |
|----------------------------|----------------------------|---------------------------------|---------------------------------|-----------------------------------------------|
| 79.442                     | 104.58                     | 98.632                          | 105.52                          | 166.1                                         |
| 79.911                     | 106.22                     | 100.76                          | 106.94                          | 178.38                                        |

5
### Table 6. Mass of Solar Panel Structure

| Massa (kg)                  |       |
|-----------------------------|-------|
| Solar Panel Solid 6 mm      | 4.246 |
| Solar Panel Solid 8 mm      | 5.661 |
| Solar Panel Isogrid 10 mm   | 4.862 |
| Solar Panel Orthogrid 10 mm | 4.020 |
| Solar Panel Honeycomb Model | 1.504 |

Freq.  
3rd Natural Freq.  
218.84  277.92  276.49  272.58  583.66
3.2. Effect orthogrid and isogrid model of solar panel structure

This section performs the influence of geometry of solar panel structure which is orthogrid and isogrid models. The thickness of both these structures is 10mm.

From Figure 5, it can be seen that the shape modes of both the orthogrid and isogrid models are the same, but the solar panel structure with orthogrid model has a higher frequency value as can be seen in table 5. By changing the geometry from solid sheet into isogrid and orthogrid and keeping the same material properties, the natural frequency is not much different from orthogrid model, but higher than isogrid model as can be seen in table 5. However, the mass of the solar panel structure with isogrid and orthogrid model is lower compared to solid aluminium sheet even with thicker thickness.
Figure 5. Mode shape of the a. isogrid model b. orthogrid model

3.3. Effect of changing aluminium solid sheet ke aluminium honeycomb model

In this subsection, considering changing aluminium solid sheet into aluminium honeycomb model bring massive impact on not only in natural frequency but also on mass. The natural frequency is increasing yet the mass is decreased. The model shape can be seen in figure 6.
4. Conclusion
Modal analysis is the basic requirement for the solar panel structure design which is can calculate the natural frequency of solar panel structure with three different models as follow: aluminium solid sheet, aluminium isogrid and orthogrid model and aluminium honeycomb model. The different results obtained in this paper show that all of solar panel structure models have fulfilled the natural frequency of LauncherOne requirement, however, the honeycomb model gives the best option as a solar panel structure on a constellation satellite due to it has the lowest mass. The mode shapes from the modal analysis can be used as a reference to lay the accelerometer when testing and measuring natural frequency of the structure on vibration test machines.

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