Integrated Design of Solar Panels Deployment Mechanism For a Three Unit Cubesat

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CubeSats are a cost effective way to demonstrate scientific and technological experiments in space. One of the restraining factors is the limitation in generation of more power which restricts the fully utilization of the potential of CUBESATs. The generation of more power would mean increasing the life of the satellite and allowing more complicated power consuming instruments & equipments to be tested on-board. There is substantial research going on in developing cost effective methods to deploy solar panels to generate more power like miniature motors, Torsion spring and Shape Memory Alloys (SMAs). This paper will discuss in detail the design and successful implementation of Integrated Solar Panel Deployment Mechanism (ISPDM) using torsion springs and micro-levers. The design is not only in accordance with Cubesat Design Specifications (CDS) but also assures minimal extra mass and the best utilization of a three unit CUBESAT's area. This design is equally applicable to a single and double unit CUBESAT.

I. Introduction

WITH the advancement in satellite technology, CubeSats technology is also getting sophisticated. Research organizations from all over the world are focusing on testing their products and technologies on low-cost CubeSats. The advantage to test new technologies on CubeSats is that they are low-cost and their launches are very frequent. For example, if a company wants to test its newly developed solar cells, instead of testing those solar cells on a full scale mission they can test them specifically on a Cubesat. CubeSats can provide limited power to the bus due to limited number of solar cells. Therefore it is required to provide more power to the bus so that it can deliver power to the subsystems and the research equipments. Many solutions have been put forward for the deployment of solar panels for e.g. miniaturized motors[1], extendable solar panels[2] and Shape Memory Alloys[3].

This paper will discuss a new design approach with which one-shot extendable solar panels can be deployed. The design has been made using the classical torsion spring-loaded technique which conforms to the rigid mass and volume of the CubeSat design specifications made by PolyCal[4] . The design has been successfully developed and will be discussed in detail in later sections.

II. Design Overview

The design of ISPDM is a multi-panel deployable solar array panel, it's simple yet reliable and fits within a 3U CubeSat (10cm x 10cm x 30cm) and subsequently can also be implemented to a 2U (10cm x 10cm x 20cm) and 1U (10cm x 10cm x 10cm) CubeSats. ISPDM integrates the levers used for deployment of the panels in the rails of the CubeSat. The design adheres to all the specifications provided by PolyCal Specifications.

A. Design Requirements

The innovative design requirements are mentioned below:

1) Pyrotechnic methods should not be used.
2) Provide a light-weight solution for the deployment of solar panels.
3) It should be deployed to get maximum solar angle.
4) Solar array shall have passive deployment and locking mechanisms
5) Should be within the specifications provided by CDS.
6) Able to withstand the mechanical stresses spacecraft is exposed to.
7) Easy to fabricate and easy to assemble.

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8) Fulfill the deployer's and launcher's requirements.

B. Deployment Mechanism Design

The structural design was kept simple but reliable. Since mass of the satellite should also be kept within a range, therefore the mass of the deployment mechanism was of main consideration. And to keep the mass within limits (although there is no limit for the deployment mechanism alone but other scientific instruments are of main concern w.r.t mass considerations) minimum number of parts was designed. The main design calculations were for the torsion spring. First there were some initial assumptions such as the force required to deploy the panels and the diameter of the spring. Having these assumptions initialized the analytical design of the spring was carried out which is as follows:

1. Calculations for the torsion spring

a) Assumptions:

To calculate the spring parameters some assumptions were made which are as follows:

Moment of the spring, M: 5 [N.mm]
Final Leg Position φ_{final}: 135^o
Stressed Leg position $\varphi_{stressed}$: 180^o
Unstressed Leg position $\varphi_{unstressed:}$ 0^o
Force applied by each spring, F: 0.5 [N]
Internal Diameter of the spring, D_i= 3.2 [mm]

Material properties of spring:
Type: 1.4310 X10CrNi188 Stainless steel V2A, High corrosion resistance.
Max. Operating Temp.: 270 [^{o}C]
Young's modulus of elasticity: 190,000 [N/mm^2]

b) Parameters of the Torsion Spring

A typical torsion spring is shown below. There are a wide variety of coil end configurations to suit different applications and a torsion spring is usually positioned on a shaft. The coils are usually close wound and do not have any initial tension unlike tension springs.

The primary stress induced in torsion spring is a bending stress in the wire. During forming residual stresses are built up in the winding process. These residual stresses are in the same direction but of opposite sign to the working stresses resulting when the spring is loaded causing the coils to tighten. Torsion springs are stronger as a result and they are often designed to work at, or above the yield strength.

Where:
F: is the force applied [N]
R: is the length of the leg [mm]
D: is the diameter of the spring [mm]
d: is the wire diameter [mm]

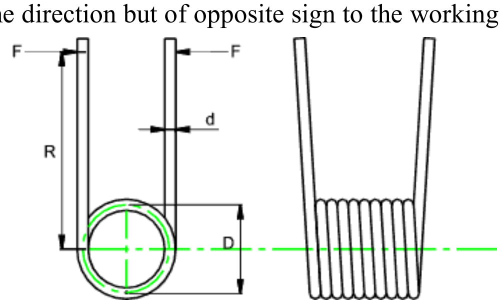


Figure 1 Torsion Spring

c) Calculations

The following sets of equations are used to find the required spring parameters:
Approximate diameter of the wire of spring; d [mm]

$$d = ((0.23)\sqrt[3]{M})/((1-0.06)\sqrt[3]{M/D_i}) \tag{1}$$

Calculating the number of turns required; n

$$n = ((\varphi^{o}_{final})(E)(d^4))/((3667^o)(M)(D)) \tag{2}$$

Length of the spring body when relaxed; L_{ko} [mm]

$$L_{ko} = (n + 1.5) * d \quad (3)$$

Spring stress concentration factor co-efficient; K_i

$$K_i = ((D_i + d)/(d + 0.07)/((D_i + d)/(d - 0.75) \quad (4)$$

Calculating the bending stress; σ_q [N/mm^2]

The primary stress induced in torsion spring is a bending stress in the wire. The maximum bending stress is at the inner fiber of the coil and equals:

$$\sigma_q = (K_i)(M)/((\pi/32)\ (d)^3) \quad (5)$$

Stretched length of the spring; l [mm]

$$l = n * \sqrt{(((D_i + d)\pi)^2 + d^2))} \quad (6)$$

Calculated Rotation Angle; $\varphi_{calculated}$ [degrees]

$$\varphi_{calculated} = (180^o/\pi)(M)(l)/((E)(\pi/64)(d^4)) \quad (7)$$

The angular spring rate; k_a [N.mm/rad]

$$k_a = (E)(d^4)/(64(D_i + d)(n)) \quad (8)$$

Time required to deploy; t [s]

$$E_{potential} = (1/2)(k_a((\varphi_{calcualted})(\pi/180))^2 \quad \textbf{[Joules]} \quad (9)$$
$$J = (1/12)m(a^2 + b^2) + mr^2 \quad \textbf{[g.mm}^2\textbf{]} \quad (10)$$
$$\omega = \sqrt{((2E_{potential})/J)} \quad \textbf{[s}^{-1}\textbf{]} \quad (11)$$
$$t = (2\pi)/(4\omega) \quad \textbf{[s]} \quad (12)$$

Where $E_{potential}$ is the potential energy stored in the spring, J is Mass moment of inertia of the Solar Panel, ω is the frequency and t is the time required for the panels to deploy at 135^o.

d) Results

The results from the above equations are summarized in the table.

Table 1 Results

Parameters	Values
d [mm]	0.4
n	10
L_{ko} [mm]	4.6
K_i	1.1
σ_q [N/mm^2]	875.352
l [mm]	113
$\varphi_{calculated}$ [Degrees]	135.58
k_a [N.mm/rad]	11
t [seconds]	0.341

Another important factor to be considered is whether the panel will be deployed with the applied force or not. This can be found out if we know the co-efficient of friction 'μ' between the spring and the axle about which the panel would rotate. Let's assume the torsional spring arm contacts the lever at a distance c = 7 mm from the axle centerline, applying a force F1 (1N) to the lever at the contact point. Let's assume the axle coefficient of friction is μ= 0.20, and the axle diameter is D= 2.8 mm. If (c - 0.5*μ*D) > 0, it indicates the panel will rotate when force F1 is applied. Co-efficient of friction between stainless steel and aluminum is toughly 0.45.

Therefore, (7[mm] – 0.5*(2*0.45)*2.8[mm]) > 0

5.74 > 0

This shows that the solar panel will deploy if a force of 1N on each side of the panel is applied.

C. Design of Latch and Release Mechanism

For latching the panels a simple solution by using a fishing line to hold down was used. The latch and release mechanism is still under development. But for testing purpose a temporary solution was developed to test the deployment mechanism. For this purpose a circuit was designed in which ISOTAN®, a resistive wire, was used in a loop type shape through which the fishing line was passed. Once the circuit was switched on the resistive wire melted the fishing line and the panels are deployed. The circuit diagram can be seen in the figure. The circuit is self-descriptive, as can be seen that a supply voltage is connected to the resistive wire and the resistive wire is connected with the MOSFET. One of the legs of MOSFET is connected to a 180 Ω resistor. The switch is connected to the microcontroller is shorted when a 3.3V is applied. The fishing line is passing through a loop of the resistive wire and when the circuit is switched on the current passing through the resistor heats it up and melts the wire.

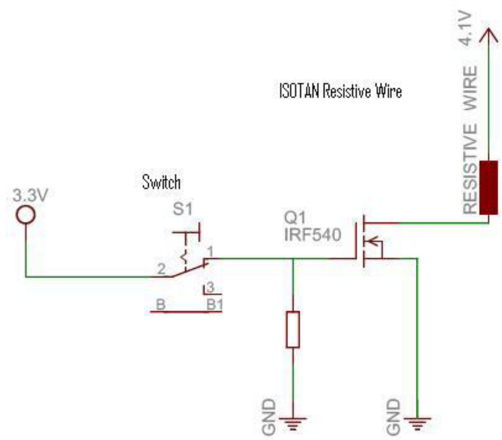


Figure 2 Schematic diagram of release mechanism

III. CAD MODEL

After the completion of analysis and calculations a Computer Aided Design (CAD) was made which would lead to the process of fabrication. The design was made using the software tool *SolidWorks Students Design Kit 2008*.The design of the structure consisted of the following main parts:

- Deployment Bars
- Supporting Bars
- Levers
- Springs
- Rest of the satellite structure

A. Deployment Bars

These are the main bars which actually bears the maximum stress during the deployment of the solar panels since it embeds almost all the other parts in it therefore it is a critical part. Also the lever stops with a sudden shock at the end of the deployment. Therefore, this part should be able to bear the shock loads without breaking or deforming. The bar was designed according to the specifications provided by CDS. It is also the main supporting bar for the whole satellite structure. The CAD model for the part can be seen in the figure.

Figure 3 CAD of Deployment bar

Features:

- Number of Main bars = 2
- Material = Aluminum 6061 Alloy
- Mass of each bar = 94.7g

B. Adjacent Bars

This is rather a simple bar meant for providing support to the structure. It faces no effect during or due to the deployment mechanism. Therefore, it doesn't undergo any shocks. The CAD model for this bar is as below:

Features:

- Number of adjacent bars = 2
- Material = Aluminum 6061 Alloy
- Mass = 130.62g

Figure 4 CAD of Adjacent Bar

C. Levers

The purpose of the levers is to support the deployable solar panel and to rotate about an axle. This part will also undergo great shocks since it will stop against the main bars. It is rather a critical part of the whole system as it will be under continuous tension when the panel is in latch position.

Features:

- Number of levers = 4
- Material = Aluminum 6061 Alloy
- Mass of each Lever = 2g

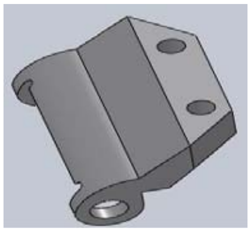


Figure 5 CAD of Lever

D. Springs

Springs will remain in tension during latch mode and it is because of these springs the panels will deploy. The CAD model is as below:

Features:

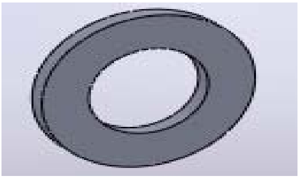
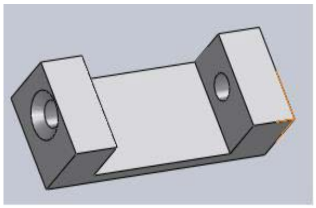
- Number of springs = 4
- Material = 1.4310 X10CrNi188 Stainless steel V2A
- Mass = 0.17 g

Figure 6 CAD of Torsion Spring

E. Other Parts

The rest of the parts include:

- Washer
- External socket
- Axle
- Deployable Panel

Part	Features
	No. of washers = 8 Material= Aluminum 6061 Alloy Weight = 0.02 g
	No. of external sockets = 4 Material= Aluminum 6061 Alloy Weight = 2.81 g

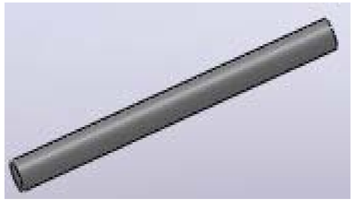
	Number of axels = 4 Material= Aluminum 6061 Alloy Weight = 0.53 g

Figure 7 Different parts of the deployment mechanism

F. Complete CAD Model and Assembly

In this section a complete CAD model of a 3U CubeSat will be shown including the satellite in the deployed and latched state.

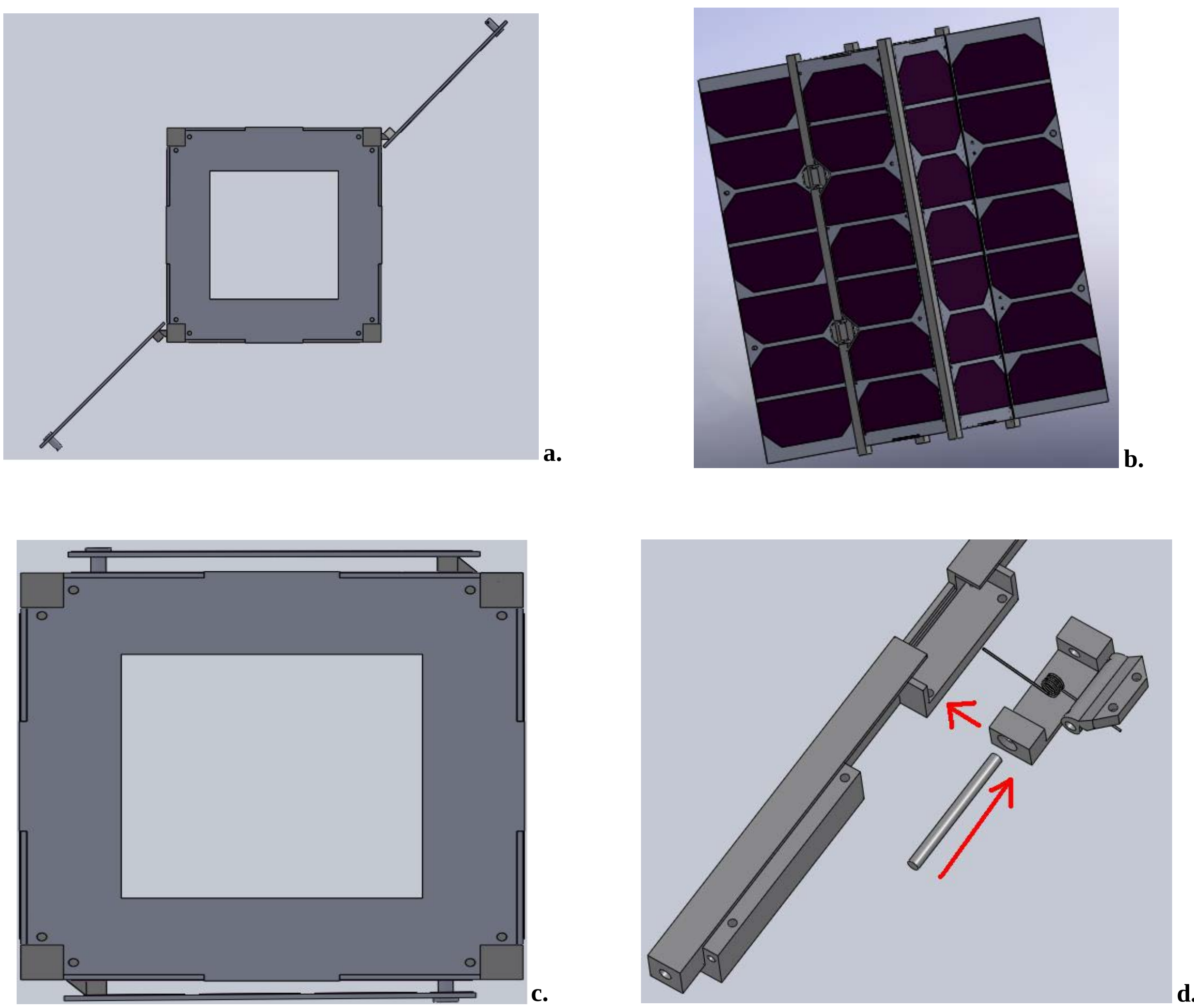


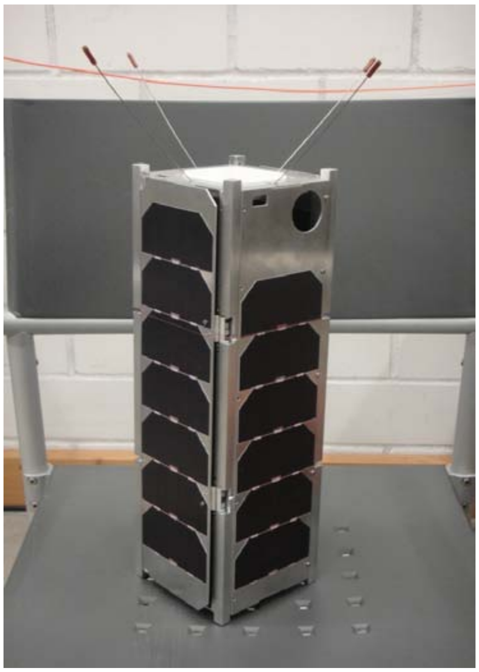
Figure 8 ISPDM CAD model: a. Top view deployed configuration; b. Front view deployed configuration;

c. Top view stowed configuration; d. Assembly integration of external socket, lever, axel and spring in the deployment bar

All the designing was completed in Solidworks 2008 Student's Kit. All the material used for the satellite's body and deployment mechanism (except torsion springs) were Aluminum 6061. The main reason to use Aluminum alloy 6061 is because it is approved for CubeSat building purpose and for other obvious reasons that it is light in weight, low density, resistance to corrosion and higher strength.

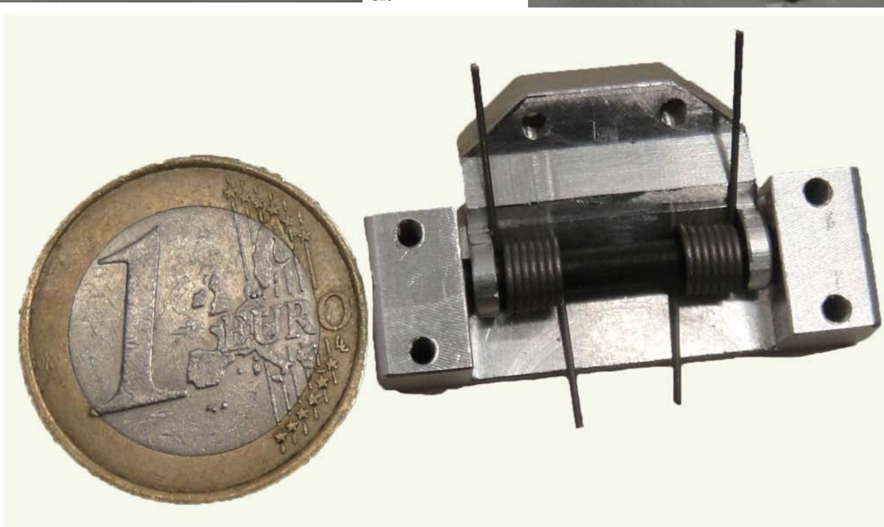
IV. Prototype

Using a CNC water jet type machine from local machine shop a 3 Unit Cubesat was manufactured as can be seen from the pictures below.



a.

b.



c.

Figure 9 a. Stowed position of the Satellite using fishing line; b. Deployed position of the panels at 135^{o};

c. Assembly of torsion springs, lever, rod and socket

V. Conclusions

This paper provides a complete design of the deployment mechanism for Nano and Pico satellites using torsion springs.

The goals achieved after are:

- Total mass of the system is 472.84 grams which is in compliant with CDS and is very economical.
- A one of a kind design of the deployment mechanism.
- Easily integrable to any 3-unit Cubesat
- With minor changes it can be integrated into other types of CubeSat as well.
- The previous problem that took a lot of time (3-4 hours) to latch the CubeSats has been solved.

This research can provide strong grounds for later researches on this topic. Although the project provides a complete design but still there is room for further modifications.

Further suggestions:

- Still there is a need for a proper damping system since without damping it can cause serious shocks.
- Actuators can be used for deployment instead of using fishing wire.
- Paraffin actuators or Shape Memory Alloys can also be used for both deployment and damping.

Another possibility is the use of ceramic heaters. The advantage for their use is that, they don't form oxides when heated up (this is important for ground testing), they are small and their electronics is simple to handle can reach up to a temperature of 700^{o}C. The main disadvantage is that they are available in 120V or 220V configurations. But they can be prepared on special orders for smaller voltages which is probably much expensive[5].

References

[1] Patrick Hoehn, *Design, Construction and Validation of an articulated solar panel for CubeSats*, ISSN: 1653-0187-ISRN:LTU-PB-EX—10/075-SE, 2011

[2] ____. "Delphi C-3" TU Delft,
Available at: http://www.delfic3.nl/, 2009

[3] University of Hawaii CubeSat

[4] The CubeSat Program, Cal Poly SLO. *CubeSat Design Specification;* California Polytechnic State University: San Luis Obispo, CA, 2009.

[5] ____. "Miniaturheizpatrone",
Available at: http://www.directindustry.de, 2009.