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THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING

WARSAW UNIVERSITY OF TECHNOLOGY

CRITICAL DESIGN REVIEW

Deployment Team

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Abbreviated terms

ADCS	Attitude Determination and Control System
AP	Argument of Perigee
AR	Acceptance Review
COMM	Communication subsystem
DT	Deployment Team
EM	Engineering Model
EPS	Electrical Power System
ESA	European Space Agency
FM	Flight Model
FRR	Flight Readiness Review
GS	Ground Station
IADC	Inter-agency space debris coordination committee
LEO	Low Earth Orbit
MA	Mission Analysis
MDR	Mission Definition Review
PDR	Preliminary Design Review
SC	Spacecraft
SKA	Studenckie Koło Astronautyczne (Students' Space Association)
SW	Software
TBC	To Be Continued
TBD	To Be Defined
TCS	Thermal Control System
WUT	Warsaw University of Technology

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

Purpose of this document is to present current development of mechanical structures on board PW-Sat2 satellite. Main activities (defined in Phase B) of the Deployment Structures Team during Phase C were:

- improvement of the deorbit sail, i.e. third C-shaped spring was added to the pocket of the sail-arm, the second variant of sail reel was chosen and improved, the final material for sail surface was selected, a connection between reel and conical spring was designed,
- final solutionof Sail Release Mechanism was chosen and developed.; the biggest progress in work of DT was done in this field
- Locking System of Container Cover was added
- Solar Arrays Deployment and Release Mechanisms were improved, the SADS position on rails was clarified, . the burning Dyneema wire system for SADS was developed

1.2 DOCUMENT STRUCTURE

Chapter 1 introduces the document, contains documentation structure, reference documents.

Chapter 2 describes results of progress done in Phase C

Chapter 2.1 describes the Deorbit Sail structure, elements and its operation.

Chapter 2.2 describes Sail Release Mechanism (SRM) which is used to release the Deorbit Sail.

Chapter 2.3 describes Locking System of Container Cover (LOCK) which is used to keep the Deorbit Sail in its container.

Chapter 2.4 describes Solar Array Release Mechanism (SARM) that is used to keep closed and open solar arrays of PW-Sat2.

Chapter 3 provides summary and planned future activities in team DT

1.3 PROJECT DOCUMENTATION STRUCTURE

See section 1.3 in [PW-Sat2-C-00.00-Overview-CDR].

1.4 Reference Documents

[1] "ECSS-E-ST-10-03C Space engineering - testing," ESA Requirements and Standards Division, Noordwijk, 2012.

[2] "ECSS-E-ST-10-06C Space engineering - Technical requirements specification," ESA Requirements and Standards Division, Noordwijk, 2009.

[3] Inter-Agency Space Debris Coordination Committee, "IADC Space Debris Mitigation Guidelines," 2007.

1.5 Applicable Project Documents

- [PW-Sat2-C-00.00-Overview-CDR] – the overview of the PW-Sat2 Phase C
- [PW-Sat2-C-05.01-DT-Structural-Analyses]
- [PW-Sat2-C-05.02-DT-Analytical-Calculations-and-Dynamic-Models]
- [PW-Sat2-C-10.00-CONF-CDR] – Configuration overview of PW-Sat2
- [PW-Sat2-C-10.01-CONF-MICD] – Mechanical Interface Control Document describing DT structures
- [PW-Sat2-C-10.02-CONF-MICD-Drawing] – Mechanical Interface Control Document Technical Drawing which includes a detailed view on the satellite
- [PW-Sat2-C-10.03-CONF-Bill-of-Materials] (spreadsheet) – Bill of Materials (spreadsheet)
- [PW-Sat2-C-11.01-Tests-Plan-Mechanical] – document describing mechanical tests of the satellite systems
- [PW-Sat2-C-11.02-Tests-Plan-Thermal] – document describing thermal tests of the satellite systems
- Assembly plans of the DT structures (see section 1.3 in [PW-Sat2-C-00.00-Overview-CDR])

1.6 Document Contributors

This document and any results described were prepared solely by PW-Sat2 project team members.

2 SYSTEM DESCRIPTION

Author: Maciej Kania

2.1 DEORBIT SAIL (SAIL)

Deorbit sail is the main payload on-board PW-Sat2 satellite. The primary objective of the project PW-Sat2 is to test this system and to verify its effectiveness. PW-Sat2 deorbit system takes the form of a square sail (2 m side). The material of the sail is stretched on four flat springs and wrapped around specially shaped center core of system. The sail will be deployed 20 cm above the satellite. Furthermore, two cameras on board the satellite will provide evidence of the sail opening moment and transmit it to the earth. That will allow us to analyze opening mechanism for future improvements and development.

2.1.1 CONSTRUCTION OF THE SAIL

The PW-Sat2 sail is a 2x2m square made from aluminized Mylar® film. In the stowed position, it will be wrapped around the cylindrical aluminum reel and held between two limiting plates inside the container. The deployment of the sail from container is based on a 300 mm long conical spring, while the unwinding of the sail is provided by the deployment of flat, C-shaped springs.

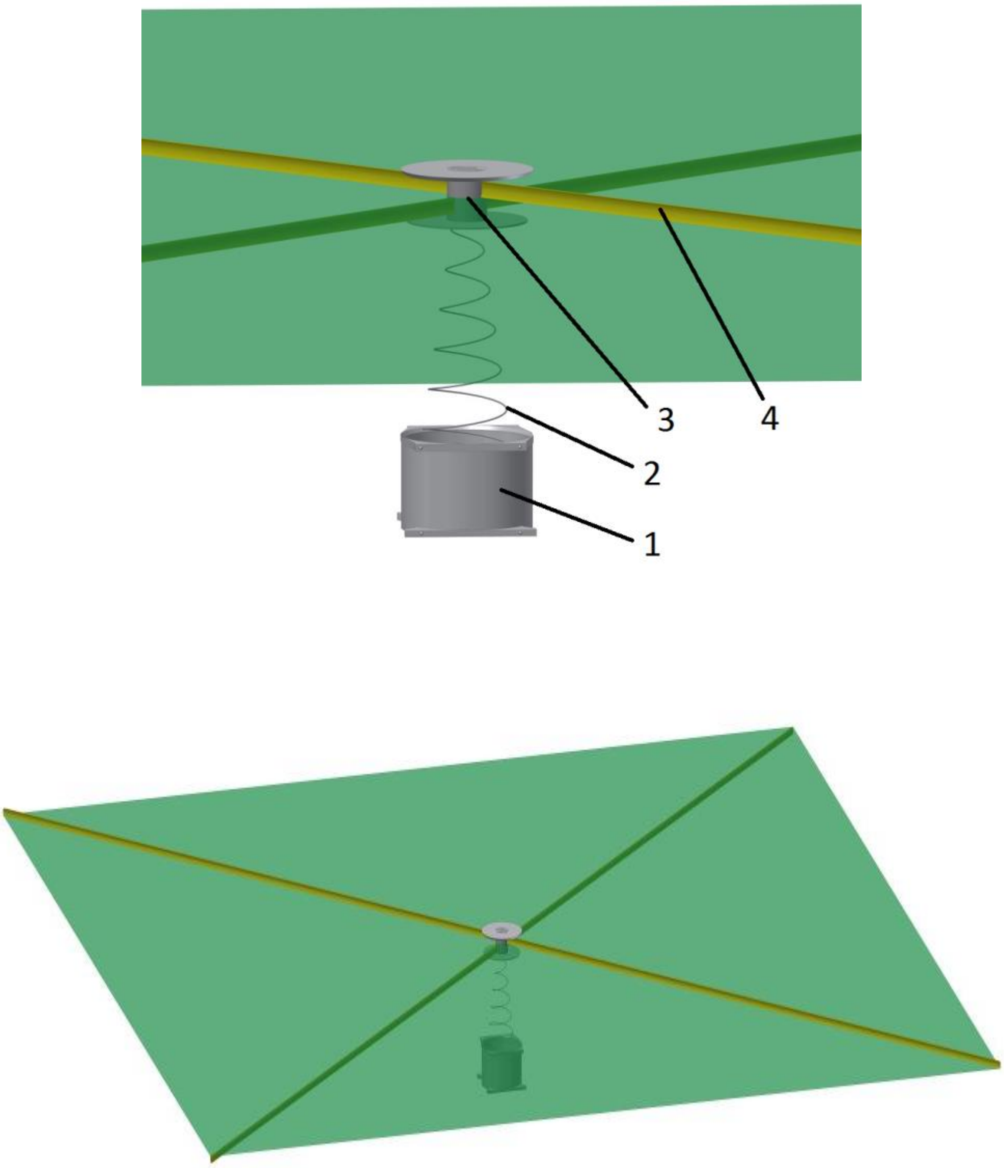


Figure 2-1 Design of the Deorbit Sail;

Left: Sail deployment mechanism close-up, (1) – sail container, (2) – sail conical spring, (3) – sail reel, (4) – sail flat springs; Right: sail deployment mechanism overview

C-shaped springs are held in four "pockets" (see Figure 2-1) attached to the sail on its diagonals. Each pocket consists two flat springs which form together the X-beam-shape. Actually is a new version of pockets tested, which contains 3 flat springs inside (see 2.1.3.) The pocket is fixed to one of the springs (internal) while the other one can move freely inside. During the winding springs become flat occupying little space. During the opening sail springs expand and take its original shape which spreads the entire structure.

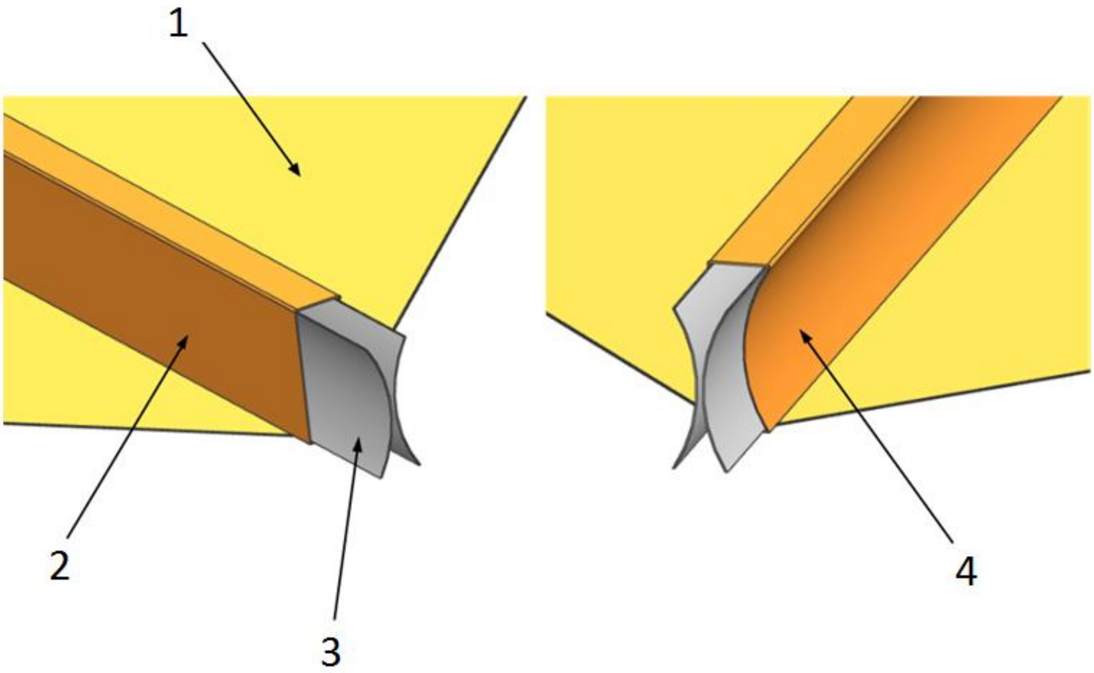


Figure 2-2 Flat springs in pocket;

(1) – sail surface, (2) – springs „pocket" – free (external) side, (3) – flat, metal springs (sail arms), (4) – springs "pocket" – glued (internal) side

Folded sail is placed in a container that enables to mount it inside the satellite. The sail is connected to the container by the conical spring. One end of the spring (a coil with the largest diameter) is fixed to the bottom of the container. The other end of the conical spring is fixed to the sail. After compression of the spring, a sail reel is attached (in addition) to Sail Release Mechanism (SRM). This mechanism keeps the folded sail inside the tank and is responsible for the sail opening on orbit. After releasing the mechanism, sail slides out about 20 cm off the satellite.

2.1.2 REEL

The reel is a canter core of sail around which flat springs are wrapped. Its purpose is to keep the springs stable during the entire mission and provide them with controlled deployment process. Since PDR only one design has been evolved and tasted. It is now fully machined instead of 3D printed.

The reel is made of Aluminum 6061. It is made of one solid part, which makes the assembly procedure easier. Its maximal diameter does not exceed 15 mm which is a big advantage.

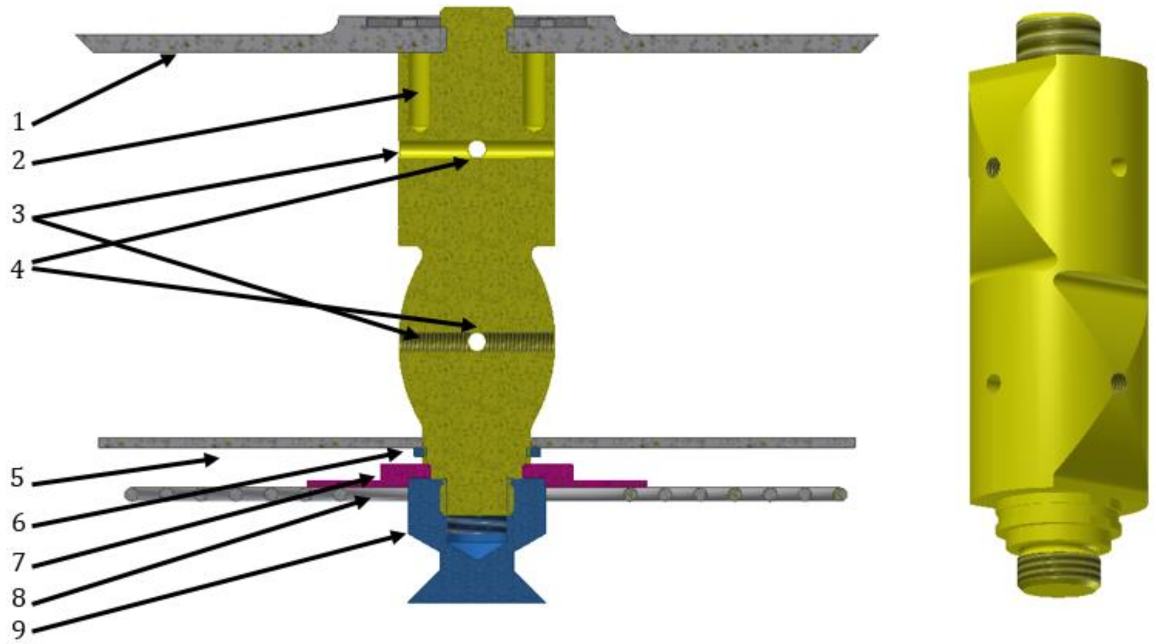


Figure 2-3 Design of the sail reel left: reel subassembly cross section, right: main reel.

1) Top plate 2) holes used during assembly of the reel in winding stand, 3) flat springs screws holes 4) vent hole 5) bottom plate, 6) Seeger ring, 7) Conical spring mountin

Special cuts on the surface of the main part of the reel are tailored to accommodate the shape of the flat springs. Springs are fastened in the cuts by the screws going through the reel perpendicularly to the springs. On top and bottom of the main part of the reel a thread has been cut to fit two plates constraining the sail material space. Top plate is used as the top cover of the sail's container, while the bottom plate separates the sail material from the container's bottom. Seeger ring holds the bottom plate, while the spring is mounted to the *conical spring mounting plate*. Arbor on the bottom of the assembly is an interface to Sail Release Mechanism.

After winding the whole sail with use of this reel variant the outer diameter of sail is below 80 mm. The problem shows during the unfolding of the sail. Flat springs which are not inside the through holes and are mounted with use of only one screw are sensitive to momentum during the unfolding. This causes the springs to easily fall out of the unwinding plane and unroll in unpredictable way. Because of this the sail cannot fully open.

2.1.3 FLAT SPRINGS

After deploying the system with conical spring, flat springs begin to unwind the sale material from the reel. When fully deployed, they spread the sail in a plane perpendicular to the Z axis of the satellite and stiffen it. Flat spring are being attached to the reel at two heights, as shown in Figure 2-4.

Figure 2-4 Flat springs being attached to the reel.

Flat springs are attached to sail material after placing them inside specially designed “pockets”.

Already is a new variant being tasted. One additional flat spring length 80 mm has been added to each “spring pocket” in between both regular springs. This invigorated side of pocket is fixed to the reel, what causes the springs to unroll in more predictable and repeatable way.

Springs form a X-shaped beam inside the pockets. Main advantages of this configuration are:

- Higher bending strength
- Bigger area of contact with sail material
- Higher stiffness

During phase B, DT made tests with different flat springs - custom made of beryllium copper and flat springs used in the production of metal rulers. Due to the fragility of the beryllium copper springs (fissures were found near reel after sail folding) it was decided to use steel springs from rulers. Such springs have been used in prior CubeSats missions and fulfilled their role.

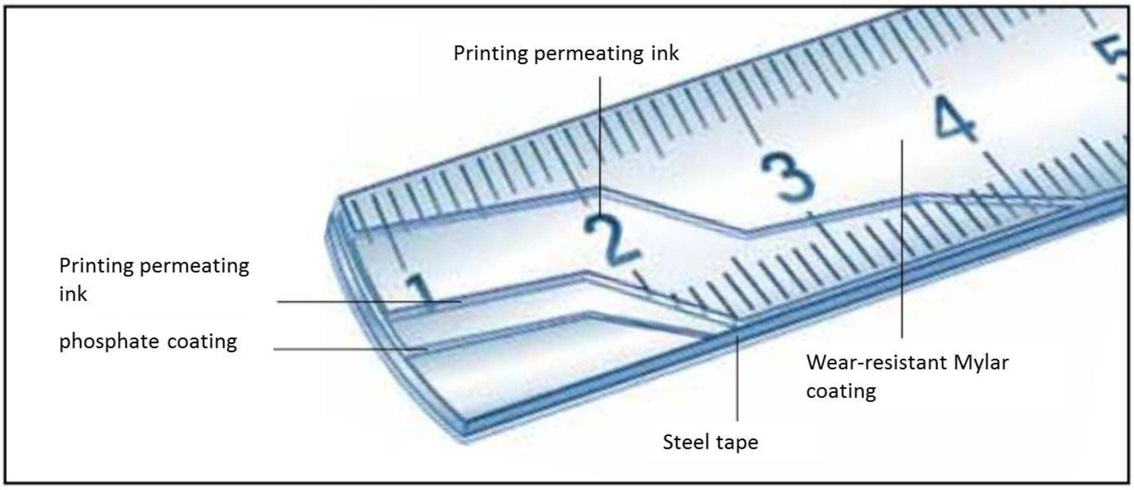


Figure 2-5 Measuring tape components.

Removal of the coating has been tested in order to try other, thicker coatings. Mechanical and chemical methods of coating removal had no good results. The steel started to corrode immediately after the operation. The original coating with Mylar® polyester film on the outer surface has been chosen to be left on the tapes.

2.1.4 SAIL MATERIAL

Material is the main component of deorbit sail subsystem. An important aspect of material selection is its low weight and low permeability. It has to collide with as many atmosphere particles as possible to increase the aerodynamic drag. The chosen material is Mylar® aluminized on both surfaces due to its heritage in similar space applications (deorbit and solar sails). The dual reflective coating avoids differential electrical charging of the sail. The material has low emittance and solar absorptance values. Thickness values, which were taken into consideration are below 15 µm. The low thickness allows to receive small diameter of folded sail placed in a container. For this reason the chosen material thickness is 6,35 µm. Its physical, thermal and optical properties are described in Table 2-1.

Table 2-1 Mylar® properties

Material properties			
Physical	Tensile strength	1830	kg/cm^2
	Elongation	110	%
	Thickness	6,35	Mm
	Density	1,39	g/cc
	Yield	124,9	m^2/kg

	Weight/Area		8	g/m^2
Thermal	Operating Temperature	Intermittent	-250 to 150	ºC
		Continuous	-250 to 120	ºC
	Shrinkage		2,1	% max.
Metallization	Type		99,99	% Pure aluminum
	Deposition		300	$\dot{A}$ Minimum
	Electrical Resistance		≤ 1	Ohms/square
Optical	Emittance		≤ 0,04	
	Absorptance		≤ 0,14	

The material meets also outgassing requirements according to NASA database: TML-WVR <1%, CVCM <0,1%.

Material with thickness of 6,35 µm is used to create sail's 4 m^2 square. However pockets, where are placed flat springs, are considered to be made of thicker (12 µm). Mylar® or Kapton film to avoid material tearing. Pockets are attached to the sail surface with double - sided Kapton tape. Such a thick material is vulnerable to very low cutting forces, which can easily occur during folding process. To prevent material tearing, it was decided to protect all of the edges of the material with Kapton tape.

2.2 Sail Release Mechanism (SRM)

Author: Maksymilian Gawin

2.2.1 Requirements and development of the system

The requirements that was set in the Phase B for that subsystem have not changed.

Requirements of SRM:

- small size
- simple design
- easy to manufacture and assembly
- small amount of energy needed to release
- high reliability
- resistant to shock

After discussions, calculations and testing almost every version of the Mechanism, the third variant from Phase B was chosen for further development.

In that solution thanks to levers, the force needed to hold the mechanism before deployment can have lower magnitude according to other variants. It also minimizes vibrations and provides more stability and safety for entire system.

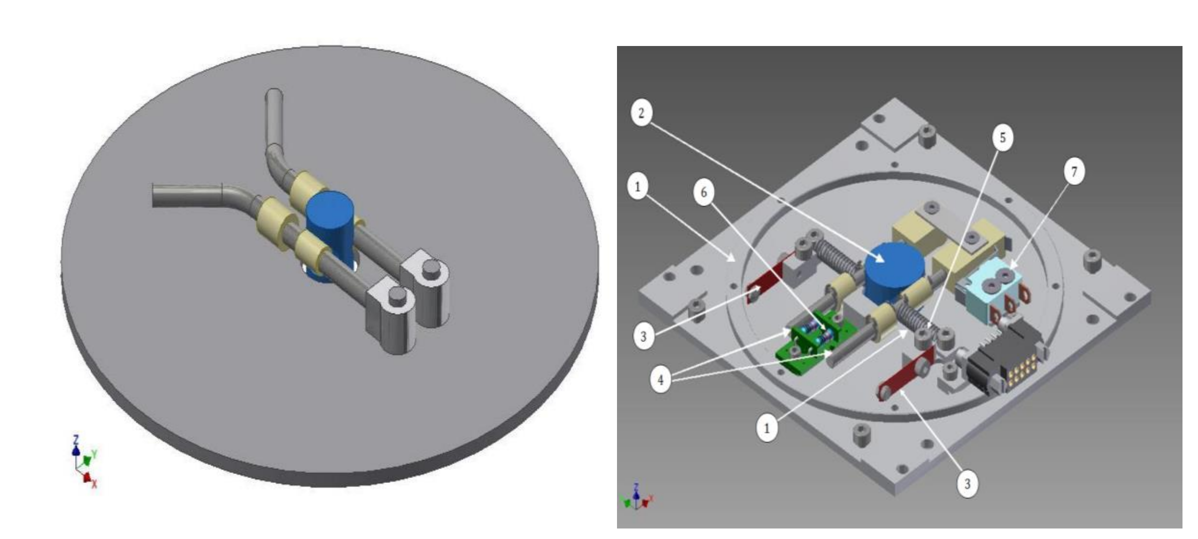


Figure 2-6 Developing of one variant of SRM chosen from the phase B;

left: SRM variant at the end of phase B; right: SRM mechanism developed during phase C 1) main board; 2) arbour – end of the sail's pin pulled out of the container; 3) flat spring keep Dyneema wire stressed with correct force; 4) levers; 5) kick-off spring, helps levers open swiftly and correctly during deployment; 6) thermal knife, burns Dyneema wire using two resistors activated by the computer; 7) switch, provides information if deployment has taken place in right time; 8) hinges

2.2.2 DESCRIPTION OF WORK

Conical spring is located under the Main Board and acts with force on the arbor. The force of the conical spring has to be compensated by the reaction force of the flat springs (3), holding the Dyneema wire.

Dyneema wire is tied around the levers and keeps them in the right distance holding the arbor. The wire is wrapped around the resistors and held by flat springs. Springs are designed and set the way that provides appropriate magnitude of force to remove backlash and hold the system before deployment notwithstanding the vibrations and congestion overloads.

In the specified time resistors burn the wire, kick-off springs help in opening the levers and the sail is to be deployed.

The switch (7 in Figure 2-6) provides information about the position of the hinge.

Performance of Sail Release Mechanism is shown in Figure 2-7.

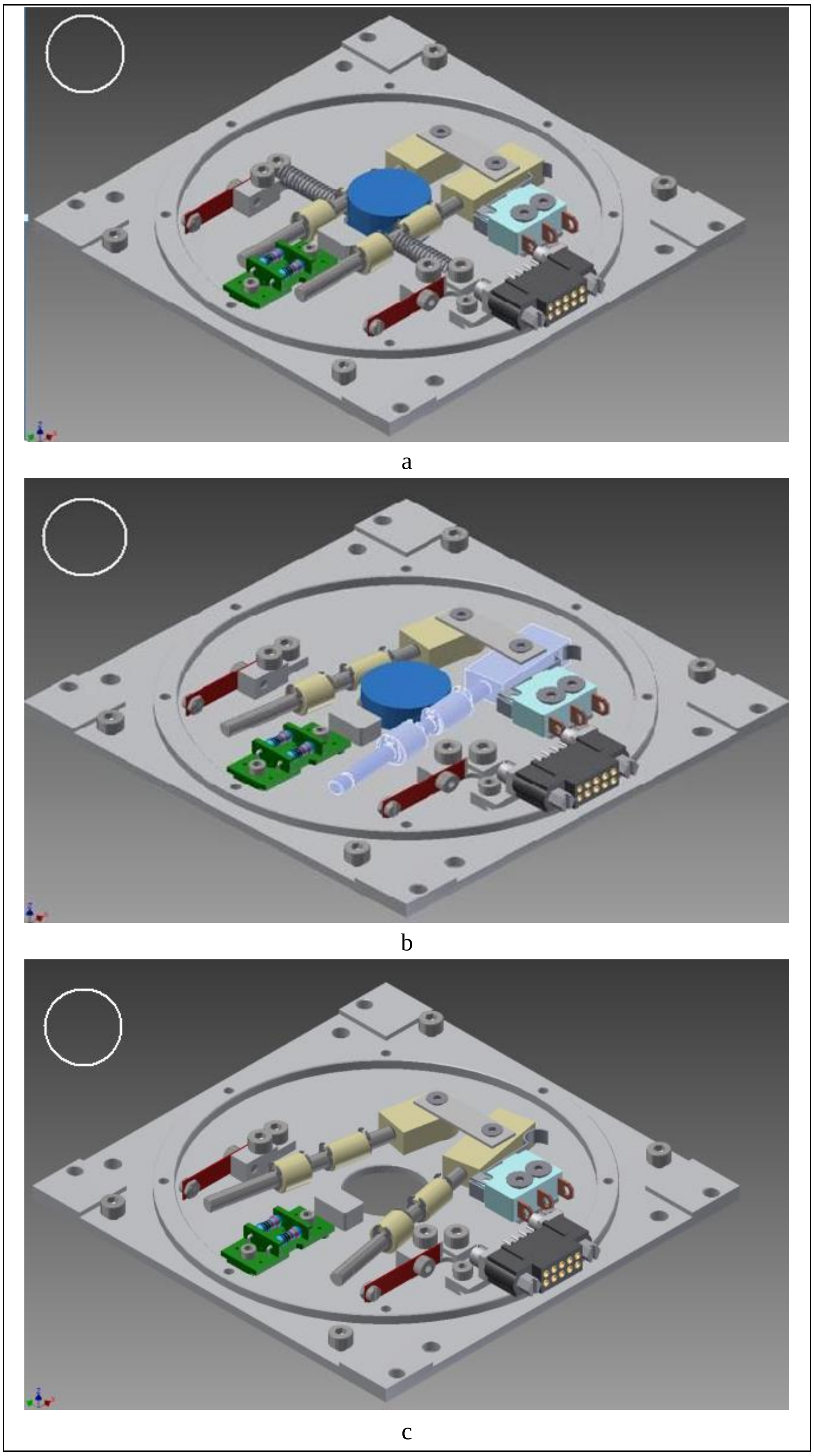


Figure 2-7 Performance of SRM

2.3 Locking System of Container Cover (LOCK)

Author: Mateusz Krakowczyk, Dominika Rafało

2.3.1 System Overview

Sail container is closed by cover, round flat disk, connected with satellite by sail reel, and pressed to edge of container by force applied by Sail Release Mechanism (see Figure 2-8).

Due to many reasons like accuracy of manufacturing, unknown size of folded sail etc., distance between bottom of container and cover should be adjustable, to get proper force of press on cover. The best solution is the screw-nut solution, where cylindrical end of sail reel is „screw” and cover, with threated hole is „nut” - it allows to regulate position of cover on reel and is simple to assembly and disassembly (also after disassembly parts are not damaged). Due to size of system, M8x1,25 thread was assumed, but diameter can be changed because of stress analysis. Also fine thread is took into concern.

The screw-nut solution has also some disadvantages. Vibration and shocks can unscrew cover and enlarge clearance between container and cover. It can be possibly dangerous for mission – axis od reel can become non coaxial with axis of container and chock sail inside container.

2.3.2 Solution

Solution of vibration problem is locking thread in cover. It can be done with a lot of solutions like using glue in connection between reel and cover, pin which can set position of cover etc. In this system that solution cannot be applied – sail system will be assembled many times, so using methods which are disposable isn't beneficial.

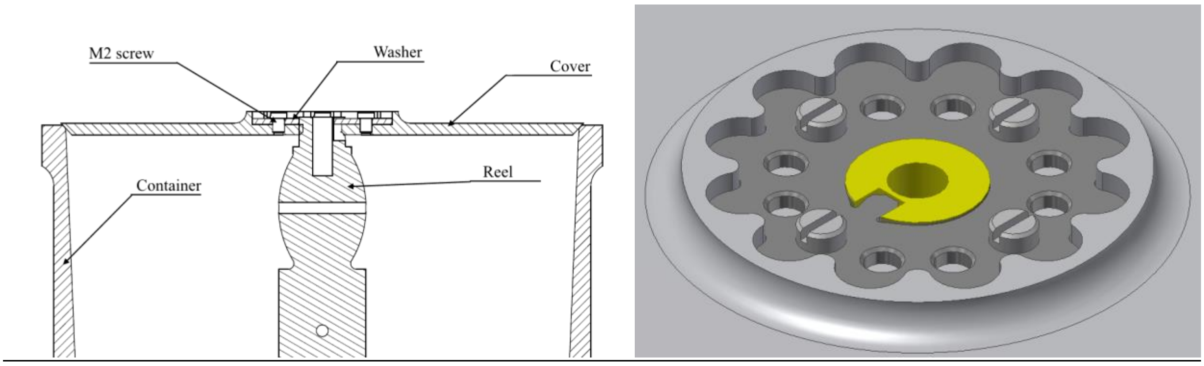


Figure 2-8 Locking system for container cover

The best way is to use method which is widely used to lock bearings on shafts. It used tooth lock washer to indispose movant of nut around screw. This method applied to this system contains special star-shape steel washer with 12 rounded arms and groove with corresponding-shape in cover. Also in cylindrical threated part of reel special grove has to be manufactured. Position of washer in vertical direction is set by four small (for example M2) screws with goes by holes in washer and are screwed to threated holes in cover (with helicoil inserts).

That solution lock the position of cover in all directions and makes connection easy to assembly and disassembly without damaging parts of system, and no manufacturing process like drilling, milling etc. is used during assembly. Position of cover in vertical direction can be changed in 0,1 mm steps by turning cover around reel – by one rotation of cover around reel there is 12 position when cover can be blocked by washer.

2.3.3 ASSEMBLY PROCEDURE OF COVER LOCKING SYSTEM

1. After putting sail in container, cover is screwed on reel to proper position
2. Washer is put on the reel
3. Cover is screw in the position, when washer can be put in corresponding grove in cover
4. Washer is screwed into cover by four M2 screws.

2.4 SOLAR ARRAYS DEPLOYMENT SYSTEM (SADS)

Author: Katarzyna Ciechowska

2.4.1 PRINCIPLE OF SYSTEM OPERATION

One of the most reliable parts in the Sail Arrays Deployment System is a spring. Thus the project of the solar panels deploying system was based on using helical torsion spring with properly matched torque. There are two springs for each hinge and two hinges for each solar panel. Solar panels are connected with hinges by sleeves which can rotate around the shaft. The outer sleeves' surface is pasted to the inner surface of solar panels. They are also screwed with two M3 bolts for each sleeve. The springs are also mounted on the shaft. One of its ends is placed in special hole in the sleeve and the other one is free, based on the rail's surface. The mechanism was designed for one, fixed opening angle. The solar panels rotate through an angle of 90° and stops on the rails surface which absorbs the impact energy.

2.4.2 SYSTEM OPERATION

1. While satellite launching into orbit and in the initial phase of the mission the solar panels are closed (adjacent to the walls) – Dyneema wire is attached to the free ends of the panels and immobilizes them
2. Torsion springs placed in the panel's hinge are subjected to pressure (the angle between the free ends of the springs is 90°)
3. Satellite receives a signal to open the panels – electric pulse is send to the resistors touching the Dyneema wire
4. Resistors heat up and the wire is burned

5. Torsion springs are opening the panels
6. The panels stop in position of 90° on the rail surface
7. Residual torque causes a continuous spring pressing and prevents the closing of the panels

2.4.3 HINGE PARTS DESIGN

In order to save the satellite side surface, the hinge structure is located inside the satellite's rail. To maintain the panels stiffness there is designed a connection of panels with the main structure by using two identical hinges. Hinges built into the rails will need to make cut-outs in the rails.

The condition of contact rails with P-POD for at least 75% of the rails surface results in restrictions of the cut-outs length in the rail:

$$w = 0{,}25 * L = 56{,}25 \; mm$$

where:

L – rail length = 225 mm

w – maximum width of cut-outs

There are two cut-outs in the rail each of 9 mm width and 4 holes ϕ5 mm. Whole cut-outs width in one rail:

$$x = 2 * 9 + 4 * 5 = 38 \; mm < w$$

The assumption is fulfilled.

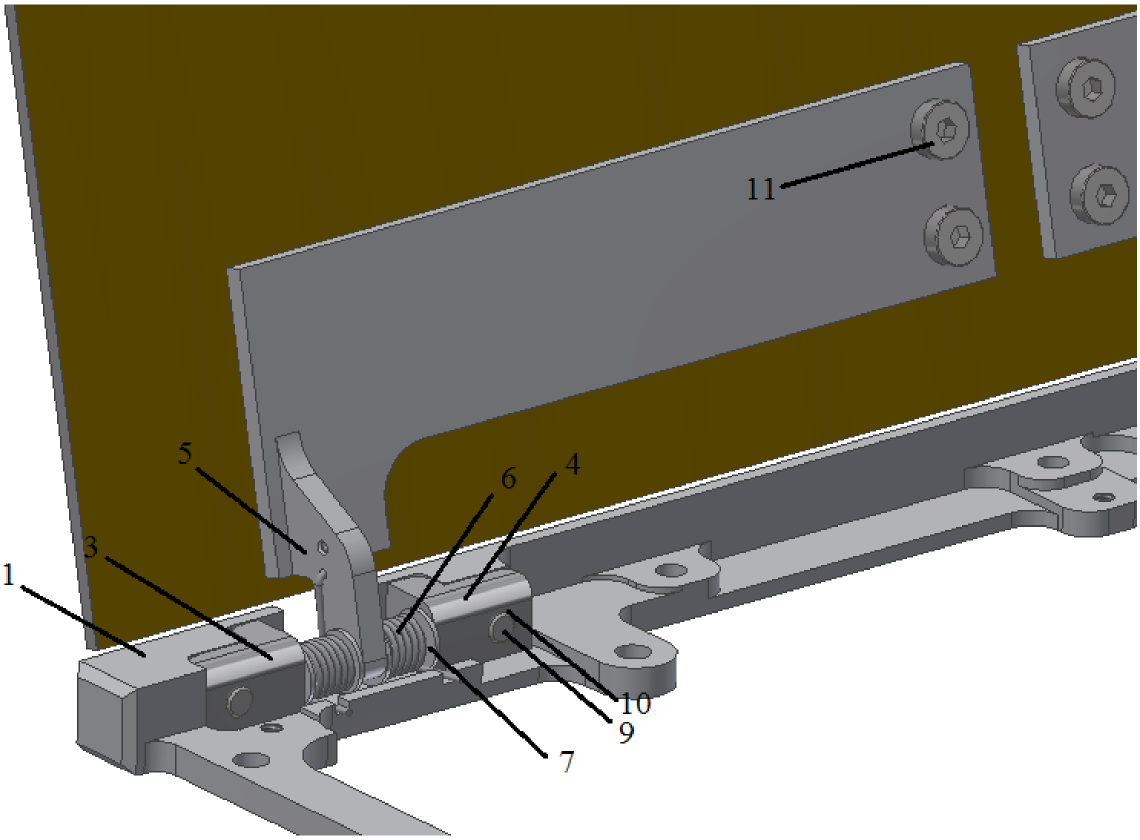


Figure 2-9 Parts of Sail Arrays Deployment System

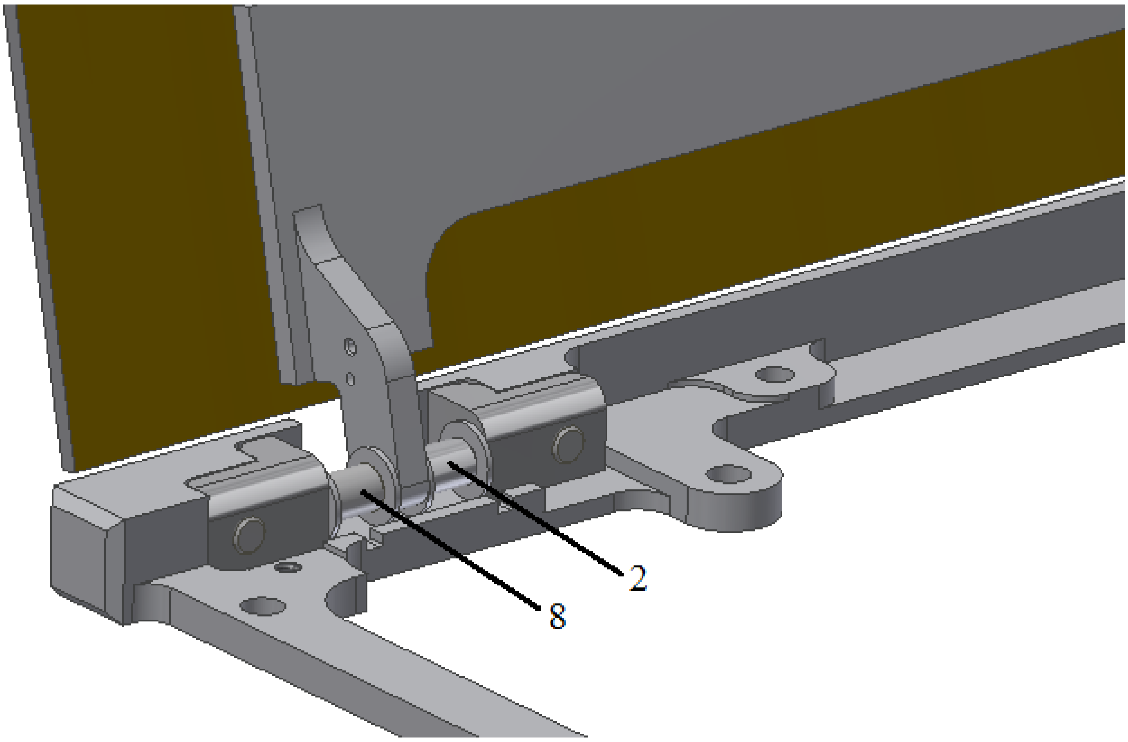


Figure 2-10 Parts of Sail Arrays Deployment System with springs hidden

Table 2-2 Listed parts of SADS

Part number	Part name	Quantity	Standard/document/comments
1	Left/right rail	2	CubeSat Design Specification/ Own design
2	Shaft ϕ2mm	4	
3	Hinge part 1 (pasted)	4	
4	Hinge part 2 (pasted)	4	
5	Sleeve	4	Own design
6	Helical torsion spring	8	PN-71/M-90057
7	Washer M2	16	
8	Sleeve M2	4	
9	Cylinder screw M2,5	8	DIN 912
10	Helicoil M2,5x1d	8	DIN 8140
11	Cylinder screw M3	8	DIN 7984
12	Hexagon low nut M3	8	DIN 936

2.4.4 MECHANISM PARTS

Table 2-3 Description of parts in SADS

Part	Description	Material
RAIL	Rail is made in the form of angle bar with full ends. These ends are required in accordance with the CubeSat standard, they are used for ejecting the satellites from the P-POD. The angle bar can definitely reduce the weight of the item. In the rail there are two cut-outs with a length of 9 mm which allows to mount the hinge of opening panels mechanism. The rail is wholly milled. The detailed rail description is located in part about satellite's configuration.	Aluminum 7075
SHAFT	The shaft performs the functions of an arbor which the hinge elements rotate around and on which the torsion springs are mounted. The shaft is covered with MoS_2.	Stainless steel 304, hardened
HINGE PARTS PASTED	Both components have a hole φ2mm to mount the shaft and through hole to mount element with rail. The elements are also pasted to the rail's surface.	Aluminum 7075

SLEEVE	The sleeve is the main element of hinge and mechanism. In its bottom part there is the through hole φ2mm for the shaft around which is rotates during the opening. There are also two holes φ1 mm for one of the helical springs endings. There are 4 different types of the sleeve. There are two longer sleeves which are located in the bottom part of rail and two shorter located in the upper part of the rail. Sleeves are connected with the solar array by two M3 screws. The outer surface of the sleeve is also pasted to the solar array.	Aluminum 7075
HELICAL TORSION SPRING	The spring causes opening of the panels. One of its free end is attached to the sleeve and second is leaning on the rail. The spring is made of round wire of carbon steel type according to PN- 71/M-90057.	

2.5 SOLAR ARRAYS RELEASE MECHANISM (SARM)

Author: Krzysztof Pilarski

2.5.1 FUNCTION

The mechanism will be responsible for holding the satellite's lateral panels during the launch phase and release them prior to the deployment. The release will be activated by a specified commend (commissioning phase is done, sun pointing works when the arrays stay closed, OPER team agrees to open the panels). The wire will be melted only after receiving the commend from ground, previously considered timing system was excluded. The proper functioning of ADCS is required to open the solar arrays.

2.5.2 DESIGN DESCRIPTION

The panels will be hold in a stowed positions by a Dyneema wire. The release will be carried out by melting a wire with a resistor. The mechanism will contain two resistors for redundancy. A tension spring will be used for keeping the wire in tension. The resistors, spring and Dyneema attachments will be mounted on the PLD. Solar arrays' attachment will be used for fixing the wire on the panels. The placement of the SARM and its main components are presented in Figure 2-10.

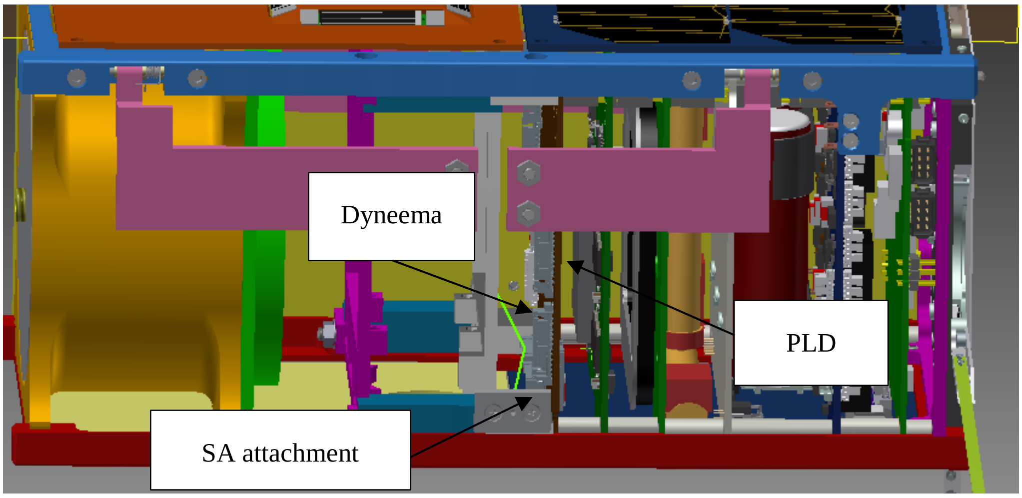


Figure 2-10 The placement of the SARM

2.5.3 PARTS ON PCB

The part of the mechanism which is attached to the PLD is presented in Figure 2-11. The mechanism covers 12% of PLD and its maximum height reaches 6.2 mm above the surface of the PLD.

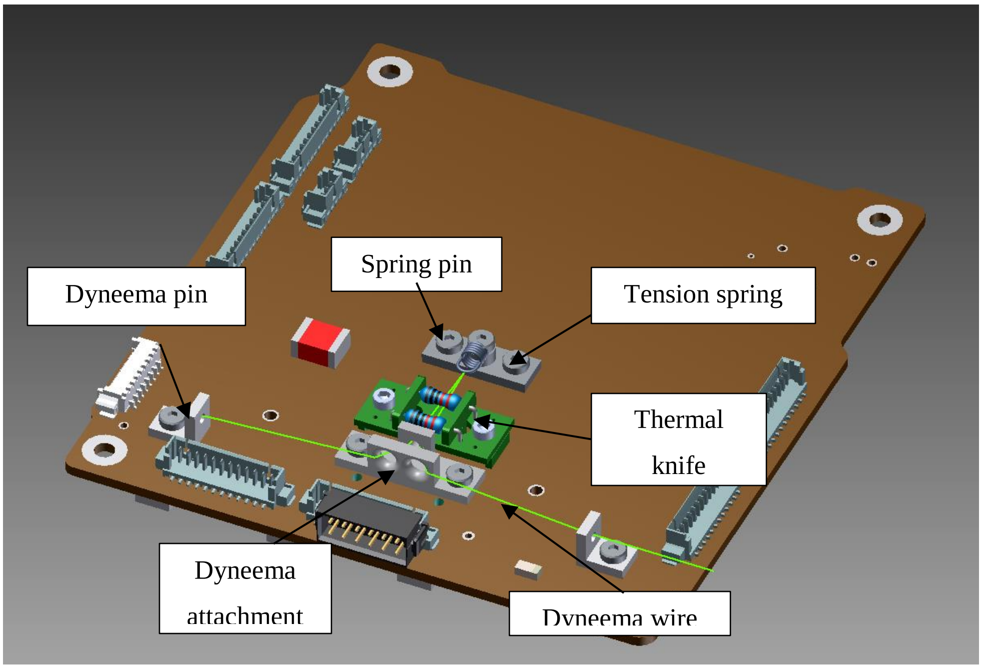
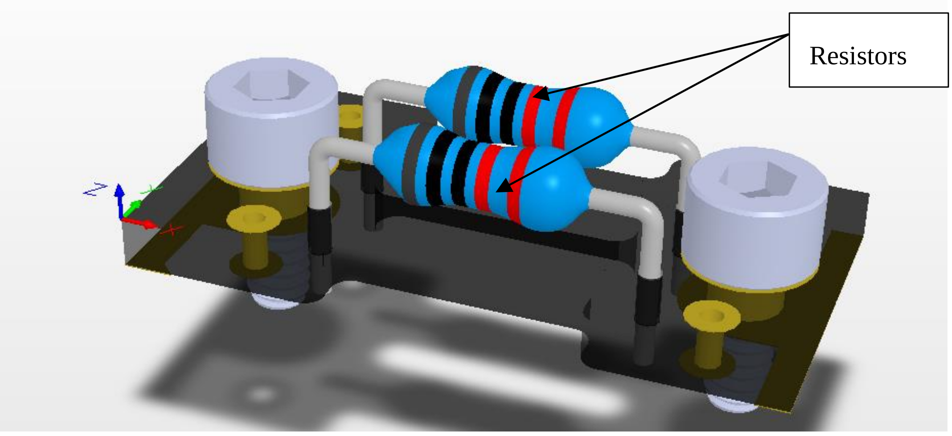


Figure 2-11 The SARM's main components

The Dyneema pins, Dyneema attachment and Spring pin are attached to the PLD PCB by means of M2 socket screw with lower head. Additionally, the movement of the Dyneema Spring is blocked with M2 screw. The Dyneema attachment has smooth edges to protect against Dyneema break. The thermal knife is attached by M1,6 screw. The thermal knife will contain THT resistors and will be designed according ECSS-Q-ST-70-08C.



5.

Figure 2-12 Thermal knife detailed view

2.5.4 Part on Solar Panel

The wire will be attached by means of Panel attachment part screwed to the panel. The proposed design is presented in Figure 2-13..

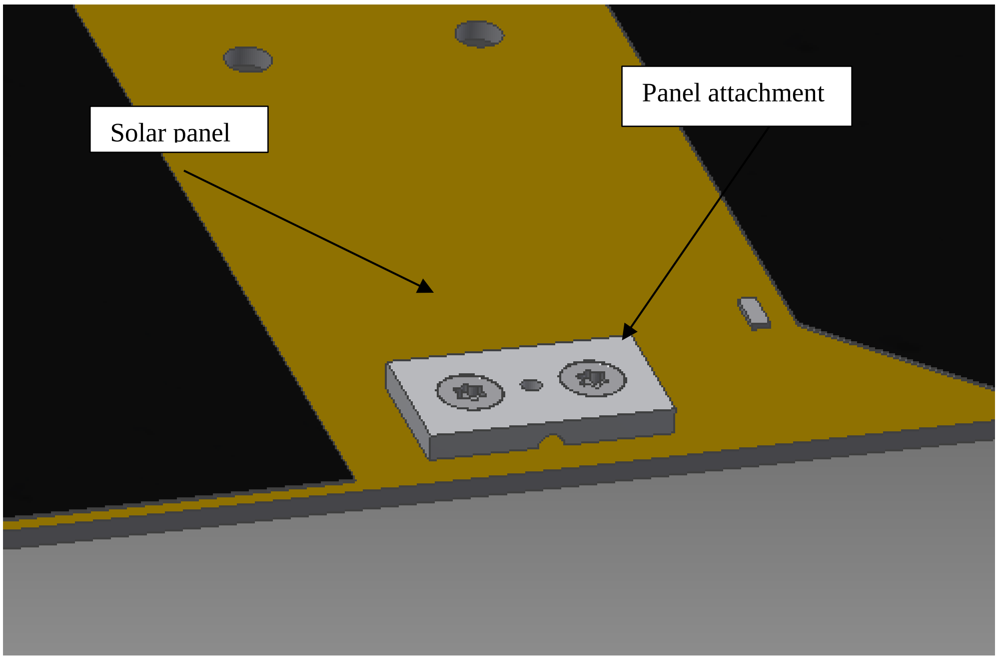


Figure 2-13 Panel attachment placement

The Dyneema wire will go through the hole in the panel before lapping the part and being tied in the middle of the Panel attachment. The section view of the part is presented in Figure 2-14.

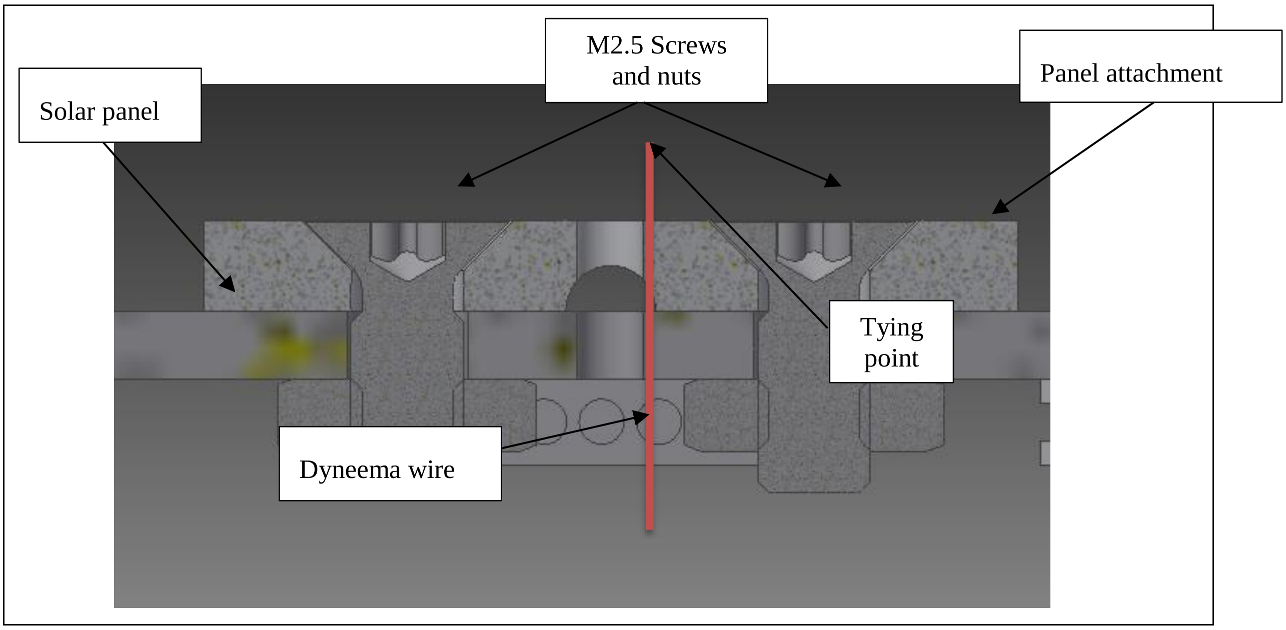


Figure 2-14 The section view of the Panel attachment

2.5.5 SPRING SELECTION

Analytical analysis was performed in order to calculate required force and choose the spring which fulfils the requirements. The spring selection was based on the mechanism geometry presented below.

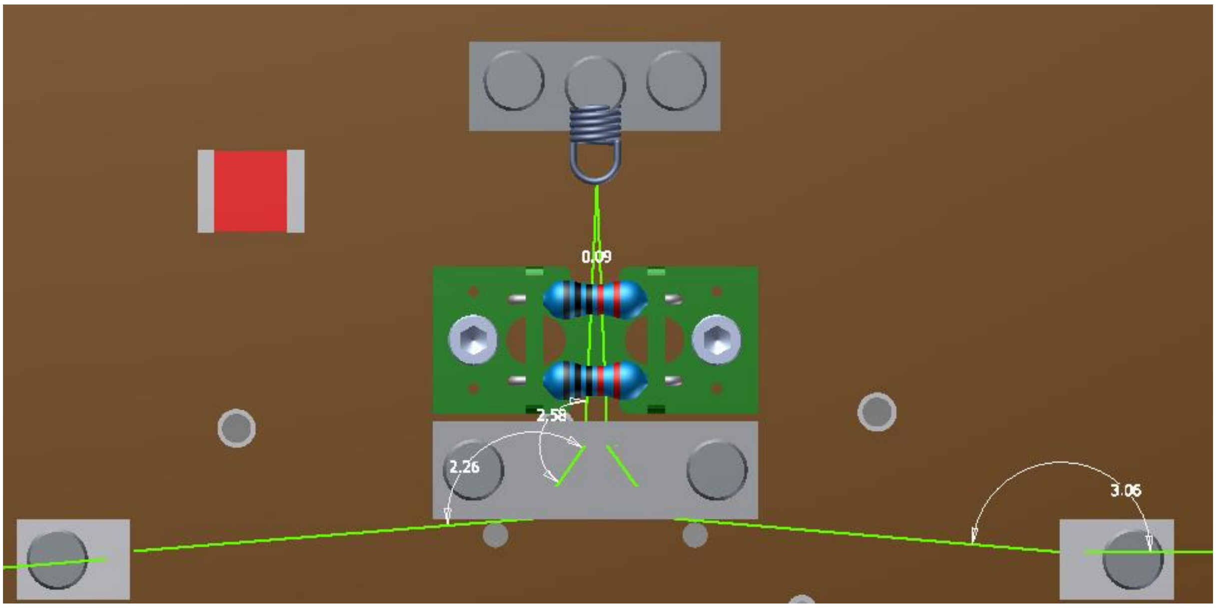


Figure 2-15 The SARM's wire geometry (angles in radians)

The maximum possible force acting along the wire was calculated. The following assumptions were taken into account:

- Single panel mass: 0,09kg

- Panel width 82,6 mm
- Center of the gravity in the geometrical center
- Hinges attachment point at the middle of the interface

The required spring force was assumed basing on the highest value of a moment that could act on the panel's center of the gravity. The force components along the wire were calculated in each turning point. Additionally, the forces acing on two panels were added. In fact, this case is impossible to occur in the reality. The force which will be opening the one panel, will be closing the one on the opposite side of the satellite. The final force will be higher than required which prevents from the undesirable opening of the panel.

Four different cases were taken into account:

- Case 1: 2g overload, safety factor 1,5
- Case 2: 5g overload, safety factor 1,5
- Case 3: 5g overload, safety factor 1,2
- Case 1: 2g overload, safety factor 1,2

The results of the calculation are presented in Table 2-4.

Table 2-4 Spring calculation results

CASE	Overload	Safety factor	Maximum force [N]
1	2g	1.5	16.5
2	5g	1.5	41.3
3	5g	1.2	13.2
4	2g	1.2	33.0

Basing on the calculation results Guttekunst's extension spring was chosen as a preferable one. Different sizes of extension spring will be tested depending on analyzed case.

The drawing of the selected spring is presented below in Figure 2-16.

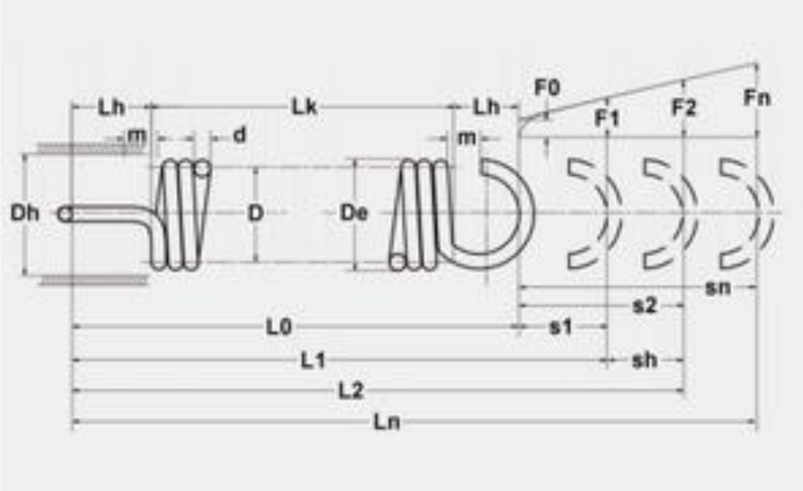


Figure 2-16 Guttekunst's extension spring

2.5.6 MATERIAL SELECTION

The following materials were chosen during design process:

Table 2-5 Chosen materials

No.	Part name	Material	Quantity	Weight [g]
1	Dyneema Pin	Aluminum 7075	2	0.226
2	Spring Pin	Aluminum 7075	1	0.397
3	Dyneema Spring	Stainless steel	1	0.311
4	Panel attachment	Aluminum 7075	2	1.089
5	Dyneema attachment	Aluminum 7075	2	0.725
6	ISO 4762 M1,6 x 5	Stainless steel	2	
7	ISO 14581 M2,5 x 6	Stainless steel	4	
8	ISO 14580 M2 x 3	Stainless steel	1	
9	ISO 14580 M2 x 5	Stainless steel	6	
10	ISO 4036 M2,5	Stainless steel	4	
11	ISO 4036 M2	Stainless steel	6	

2.5.7 FUTURE ACTIONS

The mechanism requires further studies. The position of the PLD shall be fixed in order to ultimately modify a geometry of the parts and update spring calculations. The SARM will go through vibration tests to check an accuracy of the design and choose proper spring size. Additionally, the parts will be optimized to reduce mass and occupied space.

3 SUMMARY AND FUTURE ACTIVITIES

During phase C Deployment Team tried to execute the tasks posed in phase B and solve problems and tasks arising during operation. Plenty of Deployment Structure prototypes were ordered and tasted, according many sail opening tests, SRM-tests.

There were planned sail tests on stratospheric balloon, during the flight at an altitude of about 30 km, what unfortunately didn't happen because of some external factors independent of the team.

Plenty of tests of all mechanical structures on board PW-Sat2 are planned, i.e. sail opening test under highest-quality conditions of weightlessness, comparable to one millionth of the Earth's gravitational force (10^{-6}g) during fall in Bremen Drop Tower, tests in vacuum chamber and many others.

A number of calculations and simulations were done during phase C to prove the effectiveness of developed system (see [PW-Sat2-C-05.01-DT-Structural-Analyses] and [PW-Sat2-C-05.02-DT-Analytical-Calculations-and-Dynamic-Models]).