ACTUATED COVER DOOR WITH EMERGENCY OPENING FUNCTION FOR SPACE TELESCOPES

Tharek Mohtar [1], Alessandro Bursi [1], Andrea Galbiati [1], Matteo Spinelli[1]

[1] *OHB Italia, Via Gallarate 150, 20151 Milano, Italia, Email: tharek.mohtar@ohb-italia.it*

ABSTRACT

OHB Italia has designed, manufactured, and qualified a novel Cover Door Assembly Mechanism (CDAM) for space telescopes. The main objective of the CDAM is the protection of the instrument against sunlight. In addition, it can limit the contamination from dust particles during the AIT and storage phases.

The system is composed of four main sub-assemblies: Hold Down and Release Mechanism (HDRM), actuation system, cover door, and emergency system. The HDRM is based on three separation nut actuators, needed to preload a sphere on cone separable I/F. On the other hand, the actuation system is equipped with a stepper gearmotor with redundant windings. The gearmotor rotates the 1-meter in diameter cover door for 270 degrees. In case of gearmotor failure, the emergency system decouples the actuator from the cover door. Concurrently, this system forces the cover door open. It is based on a High Output Paraffin Actuator (HOPA). When the HOPA is activated, it disengages the gearmotor and engages a preloaded torsion spring. The spring applies a torque on the cover door that opens it permanently. In this phase, the torque application is governed by an escapement mechanism.

This article describes the CDAM design as well as the results of the environmental test campaign. Special attention is paid to the lessons learned during the integration and testing of the mechanism.

INTRODUCTION

Cover doors, also known as aperture doors, are indispensable in some systems equipped with cameras. They provide protection of the instruments from contamination during the on-ground activities and launch phases. Cover doors also preclude damage from the sunlight guaranteeing shade. There are both one-shot doors and mechanisms able to close/open the door several times via an electric actuator.

An example of a motorized cover door is the one mounted on the Hubble Space Telescope [1]. In this case, an aluminum honeycomb door is driven by a permanent magnet DC stepper motor equipped with a 200:1 harmonic drive. This system can rotate the cover door at two rates; 0.23 deg/sec and 2.25 deg/sec closing the aperture within one minute.

One-shot mechanisms are normally equipped with springs that permanently open the door after HDRM release. An example is the Solar Baffle Cover Mechanism from RUAG [2]. This cover is designed as a spring-driven device with 4 torsion springs.

CDAM-CM is designed to perform several closing/opening operations exploiting a stepper gearmotor. It can close the door in 10 seconds reaching angular speeds up to 54 deg/sec.

DRIVING REQUIREMENTS

The main driver during the design of the mechanism was the opening/closing time of the cover door. The mechanism was designed to be able to close its cover door in no more than 10 seconds and open it in less than 20 seconds both in 0-g and 1-g conditions (with the motor axis aligned with the gravity vector). The door covers the ~750 mm in diameter entrance baffle of the telescope and rotates 270 degrees. When in open/closed position, the cover door shall be constrained in its position, to avoid involuntary movements during the satellite attitude maneuvers. The mechanism life requirements are 300 opening/closing cycles in orbit and 30 cycles on ground.

The most challenging requirement was the inclusion of a one-shot emergency system able to permanently open the door in case of actuator failure. Moreover, the ease of refurbishment during the ground tests was also specified.

Finally, also a lightweight design was requested. The mass requirement is < 8.5 kg.

MECHANISM DESIGN DESCRIPTION

The CDAM is an integrated system composed of a mechanical assembly called CDAM-CM (Fig. 1), an electronic box, CDAM-EU, and harness between CM and EU, CDAM-HR.

The CDAM-EU receives power and commands from the satellite and sends back telemetry regarding the status of the CDAM. The CDAM-HR interconnects the EU and CM, except for the signals/lines belonging to the Satellite Thermal Control System (TCS). All the functions of the CM are controlled and monitored by the EU through the HR.

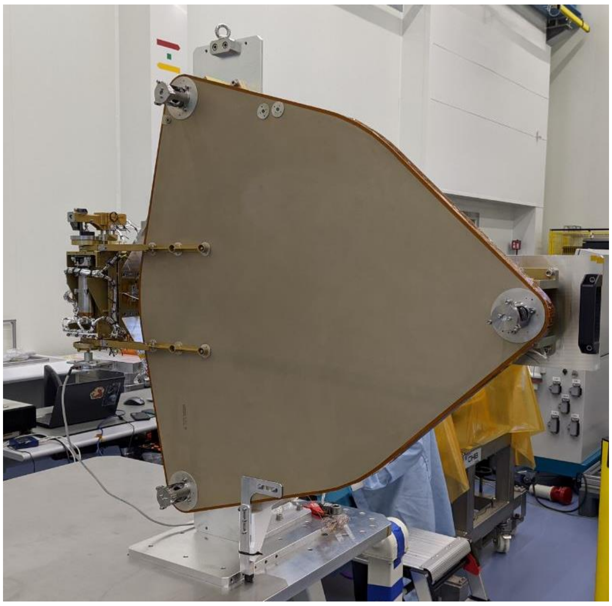

Figure 1. CDAM-CM on vertical stand with off-loading device

In particular, the CDAM-CM is placed on top of the satellite's sunshield, on the upper flange. From the functional point of view, CDAM-CM (Fig. 2) is divided into four main sub-assemblies: HDRM, cover door, actuation system, and emergency system.

HDRM: the function of this system is to hold the cover door during launch and release it when commanded. It is composed of three separate locking devices. Each locking device is based on a redundant Separation Nut Actuator (SNA) adopted to preload a sphere on cone separable I/F.

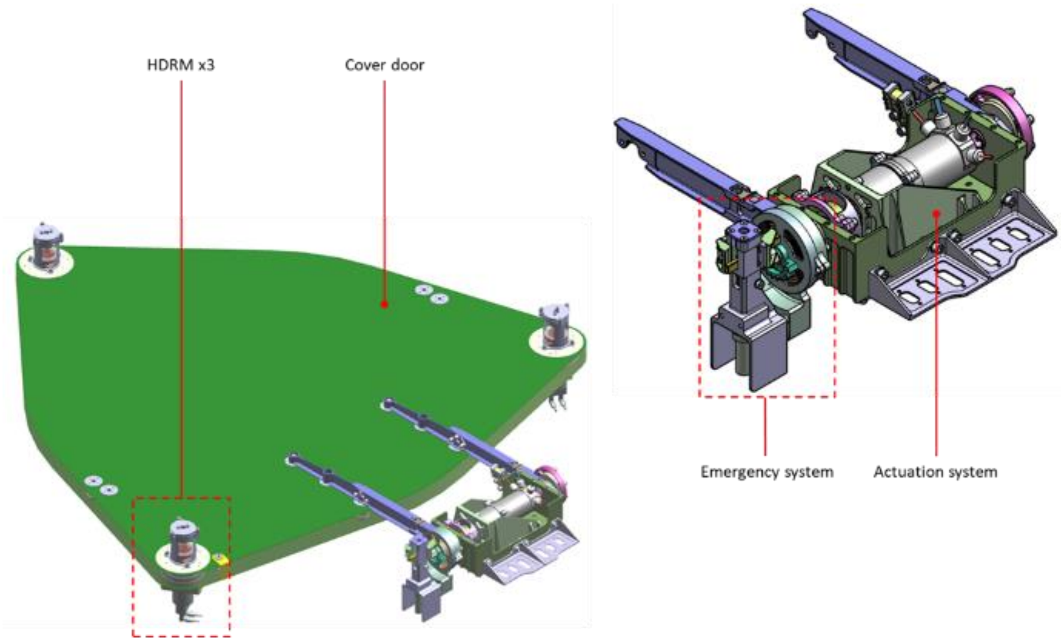

Figure 2. CDAM-CM overview

Cover door: the cover panel acts as a physical barrier against the sun. Since there is a minimum gap between the cover and the sunshield in the launch configuration, it also limits the contamination of the optics. It is a sandwich panel made of an aluminum core with aluminum skins. The panel is equipped with aluminum inserts. These inserts provide the interfaces for the HDRM and the connection with the actuation system.

Actuation system: the objective of the actuation system is to rotate the cover panel. Its main component is a hybrid stepper bipolar gearmotor. The gearmotor rotates an arm hinged to the system's support. This arm is connected to the cover panel. A second hinged arm is also connected to the cover panel and provides a stable support. This system is also equipped with a sensor suite that enables the CDAM-EU to determine the angular position of the cover panel. The sensors are 4 mechanical switches (2M+2R) to assert the OPEN and CLOSED configurations of the cover and 2 redundant potentiometers (1M+1R) to measure the intermediate angular positions.

Emergency system: in case of gearmotor failure, this system decouples the actuator from the cover panel. Concurrently, this system forces the cover open. It is based on a High Output Paraffin Actuator (HOPA). When the HOPA is activated, it disengages the gearmotor and engages a preloaded torsion spring. The spring applies a torque on the cover door that opens it permanently.

HDRM

The exploded view of one of the three HDRM is shown in Fig. 3. This space-qualified design has been used as part of the OHB-I heritage projects (MWI-LLD [3], LARES2 [4], and ICI LLD [5]).

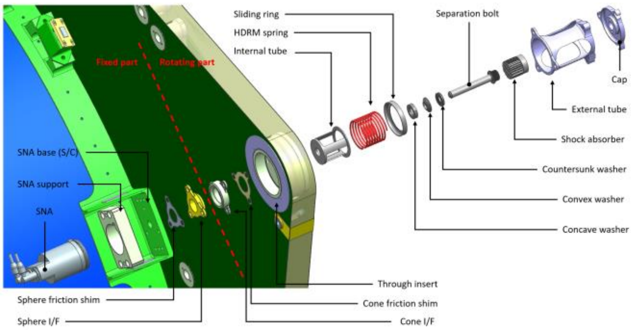

Figure 3. HDRM exploded view

The system is based on the custom Separation Nut Actuator (SNA) manufactured by Cooper Interconnect [6] for OHB-I. It is an electromechanical non-explosive actuator where the initiation is provided by two redundant electrical spools. Internally, the SNA is equipped with a threaded nut composed of 3 segments. When one of the spools is initiated, the nut segments separate freeing the fastener bolted to it.

The preload between the fixed and rotating parts is accomplished by tightening the separation bolt into the SNA (refer to Fig. 4). The tightening torque is transformed into a preload force by means of the threaded joint. This load compresses a spherical component (Sphere I/F) against a conical interface (Conical I/F). Sphere and cone I/Fs are made of hard steels lubricated using Braycote 601 EF grease. In this case, the torques applied to the sphere-cone joint by the launch environment loads are lower than the ones that can be reacted by the friction in the joint. For this reason, the joint reacts both forces and torques.

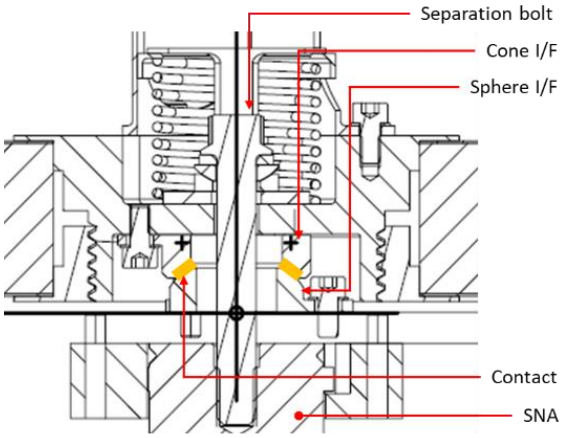

Figure 4. Sphere-cone contact interface

Moreover, both the spherical and conical interfaces are loosely bolted to the fixed and rotating parts respectively. This allows the self-alignment of the interfaces during assembly and preloading. However, to avoid the in-plane sliding of the interfaces, both the sphere and the cone are mounted on friction shims, part of the OHB-I heritage projects.

ACTUATION SYSTEM

The actuation system endows CDAM-CM with the capability of closing and opening the cover door. Fig. 5 shows the Actuation System top view.

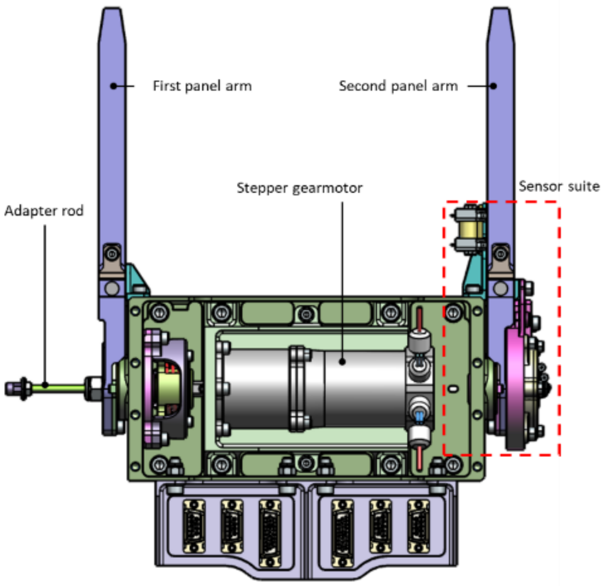

Figure 5. Actuation system top view

The main component of the actuation system is a stepper gearmotor physPACE manufactured by Phytron GmbH [7]. It is a hybrid stepper motor with 200 steps combined with a 2-stage planetary gearhead. The motor is controlled in half-step. This mode is beneficial from the vibrations point of view: each step amplitude is halved

(0.9 deg/step) so the oscillations are reduced.

The motor is equipped with redundant windings. Some of the gearmotor characteristics are summarized in Tab. 1.

Parameter	Value	Remarks
Operating voltage	30±3 V	
Phase resistance	5.2 Ω ± 10%	At ambient temperature
Phase resistance	6.7 Ω ± 10%	At 85°C
Phase inductance	5.2 mH ± 20%	
Rated current	1.2 A	
Reduction ratio	38.33	2 stages
Running torque	4 Nm	At gearhead shaft. Minimum guaranteed from 0 to 10 RPM
Motor inertia	$7.70 \cdot 10^{-6}$ kg m^2	
Gearhead inertia	$2.40 \cdot 10^{-6}$ kg m^2	
Temperature sensor	PT1000	1 on main winding + 1 on redundant

Table 1. Gearmotor characteristics

By means of the gearmotor, CDAM-CM can meet the following nominal performances:

- Close the CDAM-CM Cover in 10 seconds.
- Open the CDAM-CM Cover in no more than 20 seconds.

The Actuation System is equipped with a group of sensors as shown in Fig 6. Two 11HM1 micro-switches assert the CLOSED configuration of the system. The same is true for the OPEN configuration. Regarding the intermediate position between the OPEN and CLOSED configurations, two PRS65 A502 frameless potentiometers measure the angular position of the cover door.

The cover door is connected to the actuation system by means of two arms (refer to Fig. 5) The arms of the system are rigidly connected to flanged shafts. These shafts rotate about wrapped composite bronze flanged plain bearings coated in PTFE.

A magnetic system combined with the gearmotor detent torque prevents the cover door from rotating during the spacecraft's attitude maneuvers.

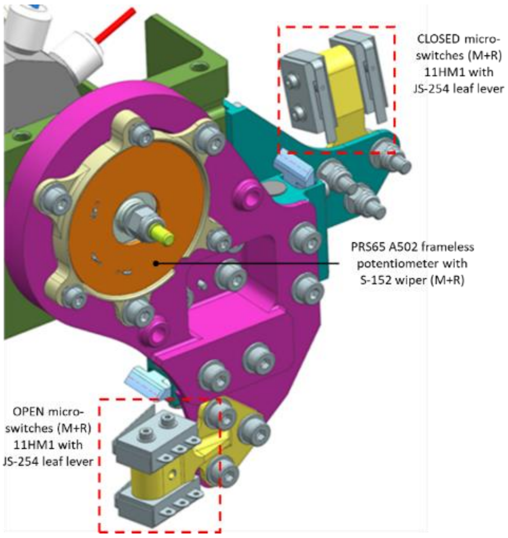

Figure 6. Actuation system sensor suite

EMERGENCY SYSTEM

In the unlikely event of a failure of the gearmotor reducer, the emergency system permanently opens the cover door. The system is based on a High Output Paraffin Actuator (HOPA) combined with a torsion spring and a toothed speed governor (Figure 7).

The activation of the HOPA pushes the HOPA piston pushing the HOPA spring. The HOPA spring maintains the position of the HOPA piston when subjected to the inertial loads experienced during launch. The unhook pin, which acts as an anti-rotation device for the piston, travels with it. The emergency spring is preloaded and is pushing against the spring cover. The cover is equipped with a toothed element that initially acts as a barrier that prevents the emergency spring rotation by pushing against the unhook pin. Once the unhook pin surpasses the first tooth, the torsion spring is free to rotate up to the next tooth. In this fashion, the energy of the spring is released in a controlled way. The spring cover is equipped with a pin that pushes against the first panel arm as shown in Fig. 8. The action of the spring on the arm forces the transition of the cover door to the OPEN configuration and, at the end of the torsion spring deployment, constrains the cover door open.

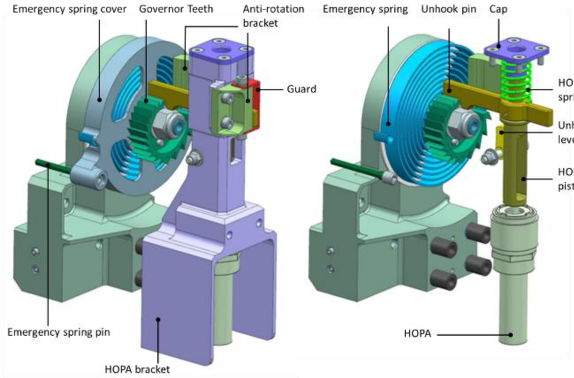

Figure 7. Emergency system

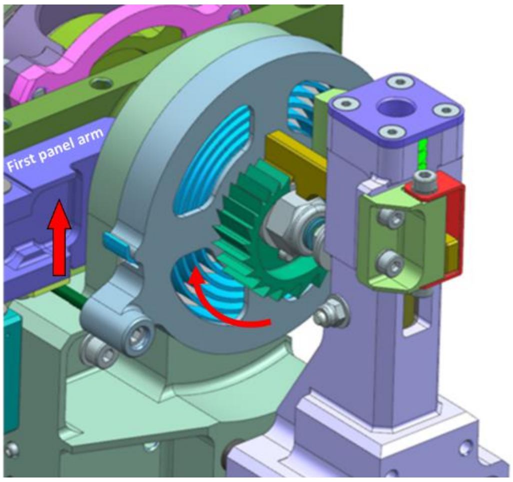

Figure 8. Emergency spring torque application

If the reducer fails, it may prevent the panel from rotating when the torque of the emergency spring is applied. For that reason, the emergency system also decouples the gearmotor axis from the panel. The unhook lever maintains the gearmotor connected to the cover door (Fig. 9). The lever is hinged to the HOPA bracket and blocked by the HOPA piston. In turn, the HOPA piston is pushed against a jacket. This jacket avoids the contact between the HOPA piston and the HOPA bracket.

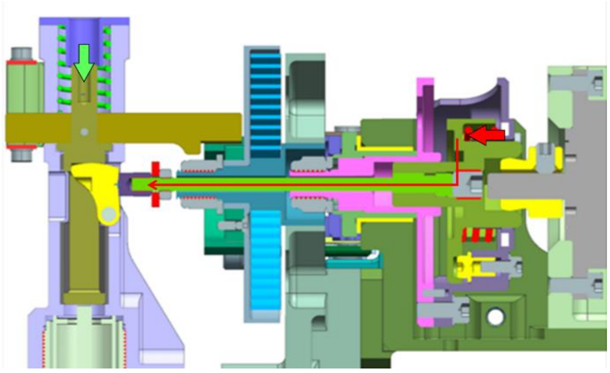

Figure 9. Initial configuration during emergency opening. The solid arrow indicates the load path

When the HOPA is heated, it pushes the HOPA piston. Firstly, the adapter rod translates outward pushed by the adapter spring as the unhook lever is free to rotate downward (Fig. 10). This separation disengages the gearmotor shaft from the panel arm.

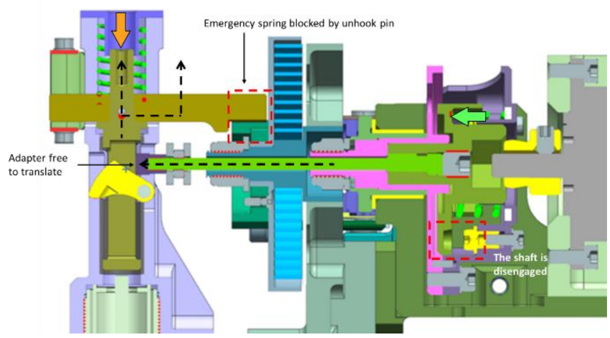

Figure 10. Gearmotor shaft decoupling. The dashed arrows indicate the direction of movement of the parts

Finally, by further pushing, the unhook pin surpasses one-by-one the teeth of the toothed spring governor. This allows the spring to rotate and push against the arm for a limited angular rotation (Fig. 11).

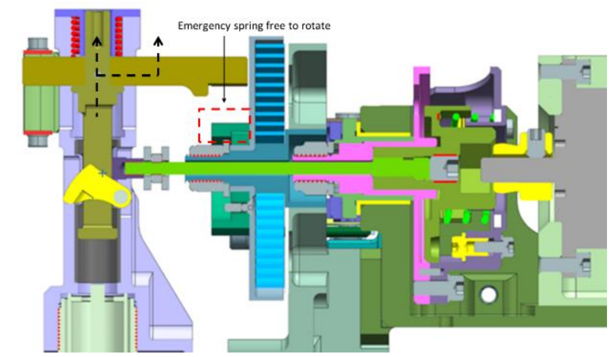

Figure 11. Emergency spring engaging. The dashed arrows indicate the direction of movement of the parts

The toothed spring governor constrains the rotation of the emergency spring to a certain angular value for each 0.6

mm of HOPA piston translation. The objective is that, regardless of the initial position of the cover door, the maximum velocity that it reaches during emergency opening is ~ 35 deg/s releasing an elastic energy of the emergency spring ~0.25 J. This limits the impact force on the OPEN end-stop.

MODEL PHILOSOPHY

The model philosophy for the CDAM development has been characterized by schedule constraints. No Breadboard development model was possible. Some heritage has been exploited for some critical parts, such as bearings (from the cage mechanism in LISA Pathfinder [8]), and HDRM (MWI LLD [3], LARES2 [4], and ICI LLD [5]).

A simplified mathematical model of the system was developed in Matlab/Simulink. Inside this model, the electrical equations of the stepper model were included to assess the dynamic behavior of the system. Moreover, a detailed ADAMS multibody analysis was also performed to verify the dynamic behavior of the CDAM CM in both nominal and emergency operations and by considering degraded conditions to assess the system sensitivity to joints friction and magnets force. Furthermore, the CDAM-CM operability in the 1-g environment has been checked.

The gearmotor was delta qualified after the EQSR, with additional tests performed by the supplier. In particular, the actual gearmotor speed-torque curve was measured at both cold and hot plateaus during a dedicated TVAC test.

CDAM Qualification Model was fully flight representative, with the only exception of connectors, which were commercial because of schedule constraints too.

Life testing was performed on the Qualification Model. Therefore, the Flight Model will not be made of any refurbished part.

QUALIFICATION CAMPAIGN

The qualification test campaign consisted of:

- Functional tests in ambient, with the aim of verifying the HDRM release and Cover Door opening and closing capabilities, including the emergency system. During this test, the motorization margin was characterized for the first time. The characterization was performed by changing the stepper motor phase current and finding the minimum current needed to move the door in the worst-case dynamic conditions.
- Radiated and Conducted ESD at 8 kV magnitude, under a discharge circuit of 150pF and 330Ω; for 15 times with a repetition rate of 1 Hz.
- Vibration test, to verify the capability to withstand an out of plane (with respect to the Cover Door) acceleration of ±30 g and in plane of ±20g during launch (Tab. 2).

QUAL SINE LEVEL Out of Plane		QUAL SINE LEVEL In plane	
Freq.[Hz]	**Acc. [g]**	**Freq.[Hz]**	**Acc. [g]**
5	1.11	5	1.11
26	30	26	20
90	30	125	20
100	20.8		
125	20.8		
Sweep rate	2 oct/min	Sweep rate	2 oct/min

Table 2. CDAM-CM sine loads

- Random vibration loads of 8.63 gRMS in plane and 10.50 gRMS out of plane.
- Shock with SRS of 2850 g (Tab. 3).

QUAL SHOCK LEVELS	
Freq.[Hz]	**SRS [g]**
100	20
2000	2850
10000	2850

Table 3. CDAM-CM shock loads

- Thermal Vacuum test, with the aim to verify the capability of the mechanism to withstand non-operative qualification temperatures +70/-60°C and to verify the functionalities, such as motorization margin, HDRM release, emergency system activation, at qualification operative temperatures +70/-50°C (refer to Tab. 4). The test was divided into two parts. The first one (Fig. 12) with the release of HDRMs just after the cumulative environmental loads (vibration and shock). The second (Fig 13), in a reduced setup without the panel, for the remaining 6 cycles, to verify motorization margin and the emergency system actuation.

Label	Description	Value [°C]
$T_{nop_{max}}$	Max, non-operational (survival)	+70
$T_{op_{max}}$	Max, operational	+70
T_{amb}	Ambient	20 / 25 °C
$T_{op_{min}}$	Min, operational	-50
$T_{nop_{min}}$	Min, non-operational (survival)	-60

Table 4. CDAM-CM qualification temperatures

Since the beginning, the reduced test setup (fig. 13) for the second part of the thermal vacuum test was considered, to allow the use of a smaller thermal vacuum chamber. The same setup was used for the life test (1260 cycles at cold operative condition, in vacuum).

- Life test, consisting of 1380 opening and closure cycles plus 24 emergency system activations, in agreement with the ECSS for cycles computations [9]. Almost all cycles have been performed in the worst operative condition, i.e., cold vacuum.

The environmental test campaign did not show any loss of performance in the mechanism (motorization margin at the end of the campaign was identical to the one measured at the beginning of the test campaign).

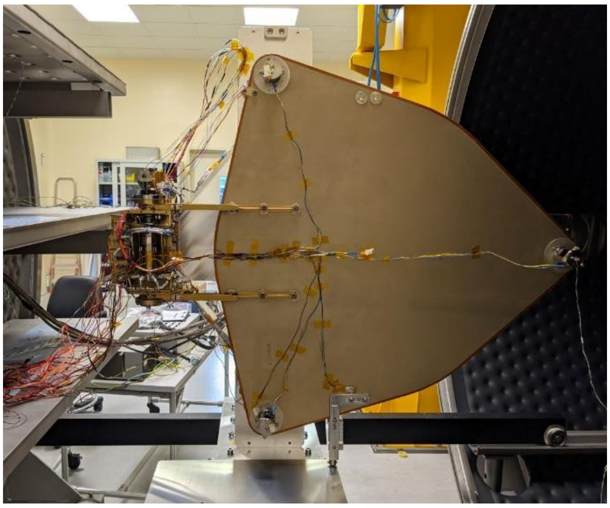
Figure 12. CDAM-CM before TVAC testing

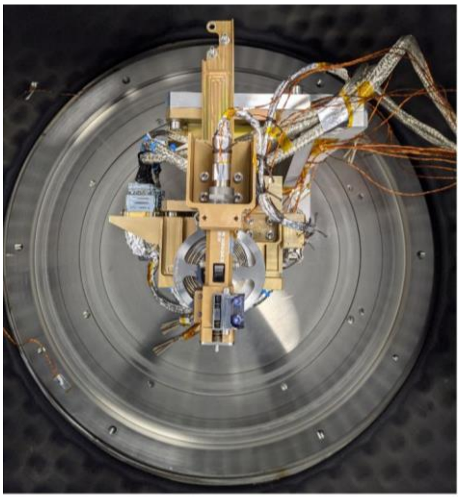
Figure 13. CDAM-CM TVAC reduced setup

LESSONS LEARNED

Due to the lack of breadboard models, some problems did emerge during the integration phase. In particular, minor modifications were added to the emergency system during this phase.

Some difficulties emerged also during microswitches fine setting due to a non-controlled fully manual positioning of the components.

The off-loading design was quite simple (a small spring-loaded suspension, moving on a plane with ball bearings as rollers), but it was rather difficult to fine-tune it, as any additional friction at the off-loading device or installation misalignment had a high influence on the minimum motor current necessary to move the Cover Panel.

CONCLUSIONS

The qualification test campaign was successfully completed in May 2021, while the flight model manufacturing is ongoing.

The absence of breadboard models did not allow the testing of some critical features before the manufacturing of the qualification model. This had an impact during the first integration phase: necessary reworks delayed this phase without impacting the delivery schedule. However, no major non-conformance emerged during the qualification testing.

Some ground segment equipment was complex in their assembly/tunning, such as that a very simple offloading (a suspension with a spring) in terms of design, revealed itself to be very hard to assemble properly.

Finally, the thermal vacuum test split into two setups was a valuable solution.

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