FOUR COVER MECHANISMS FOR ROSETTA MISSION

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ABSTRACT

Rosetta is a cornerstone mission of the ESA long term scientific programme Horizon 2000. The mission main goal is a rendezvous with comet 46P/Wirtanen aimed at the detailed study of its nucleus and its environment. On its long cruise to the comet, the spacecraft will also study two asteroids by means of close flybys.
Within the Rosetta mission, Officine Galileo is involved in three main programmes:
Navigation Camera / Startracker for the Avionics Subsystem, VIRTIS (*Visible & Infra-Red Thermal Imaging Spectrometer*) and GIADA (*Grain Impact And Dust Accumulator*) for the Payload.
All of the above equipment are provided with “Cover Mechanisms” to be deployed in various phases of the navigation. Due to the peculiar features of the mission, covers have a great importance for the good performance of the optical instruments and their protection from contamination by the comet ejected materials (dust, ice or water vapour condensating into ice, organic compounds etc.).
The present paper describes the main features of the cover mechanisms and presents some conclusions about the attempt to have a “design commonality” among these parallel developments.

KEYWORDS: Cover Mechanism, Launch Lock, Solid Lubrication.

1. COVER MECHANISMS FOR VIRTIS SPECTROMETER

1.1 Introduction

VIRTIS is an imaging spectrometer that combines three data channels in a pair of compact optical instruments. They are committed to the multispectral and high resolution spectral analysis of the comet.

The two cover mechanisms are located in front of the two instruments entrance doors. The functional purpose of the covers is double:

1) to allow the instrument in-flight calibration: when closed, the cover is inserted in the optical path of each channel and its back acts as a reflective element illuminated by internal calibration sources
2) to close the optical ports at launch and during the instrument non operative phases, in order to limit the optics contamination induced by launch and by the comet ejected materials. A sealed configuration is not required.

Key requirements of the mechanisms are:

- thermal environment: they are required to operate at a temperature of 130K during science operations and to survive a non operative temperature close to 100K during the Rosetta deep space hibernation phase.
- vibration environment: 20 g rms random
- lifetime: a repeatable use of minimum 200 open / close in-flight cycles is foreseen over a space mission period of more than ten years
- mass: less than 700 grams for each mechanism
- angular position accuracy: within ± 1°

1.2 Design Implementation

The cover mechanisms are placed on the VIRTIS Optics Module bench structure which is maintained at a very low temperature all along the mission by means of passive radiators.
Both mechanisms are composed by the same parts and components, except for the cover plates which have to match the instruments entrance doors. The VIRTIS-Mapper Channel (V-M) has a rectangular cover whose internal surface is treated with a diffuse reflectance coating for the in-flight calibration purposes; the VIRTIS High-resolution Channel (V-H) has a circular cover whose internal surface is an optical quality mirror, again for calibration purposes.
For simplicity in the following we will refer in general to the V-M mechanism.
The device consists of:

- a primary mechanism actuated by a direct drive stepper motor for multiple precise open/close operations during the mission;
- an emergency device based on a linear paraffin actuator to open the cover from whichever position in case of the primary drive failure (single in-flight operation).

1.2.1 Primary Mechanism

The mechanism configuration is shown in fig. 1.
A trade-off led to select the stepper motor as primary drive among other kinds of actuators. The main advantages are:

- suitability for cryogenic temperatures
- low thermal power dissipation
- reliability (high cycles number capability)
- good positioning accuracy
- fast actuation w.r.t. a thermal actuator

The stepper (1) is a framed configuration, including the magnetic/electrical parts, the housing and the bearings.
The motor is controlled by a dedicated electronic circuit placed inside a Proximity Electronics Module. Since the time to open (or to close) the cover is not a major performance requirement, the angular stroke between closed position (0°) and open position (72°) is computed step by step starting from the former (and viceversa).
The electronics provides also the front end to the pair of Hall Effect Sensors (2) used to monitor the end positions status (open or closed).

The light cover plate (3) is radially balanced by means of a counterweight (4) to avoid rotation during launch and vibration tests. The total mass goal of the rotating parts, including the rotor of the stepper, is 120 grams. The associated inertia is $1.5*10^{-4}$ kgm^2.

At launch the plate is maintained in closed position by the stepper motor detent torque, plus the holding torque provided by a magnet (5), fixed on the mechanism frame (6), acting against a magnetic steel lever (7) mounted on the motor rear shaft. The cover opening is assured by the adequate motor size, whose torque overcomes with a 2.5 minimum factor margin the magnet generated torque. On the other hand, during in-flight operations, the motor detent torque is deemed sufficient to keep the cover at the commanded position in spite of any external perturbation.

1.2.2 Emergency Device
Due to system constraints, the stepper motor windings and the electronics are not redundant, but a fail safe mode of the mechanism is achieved via the emergency device herewith described (refer to figg. 1, 2, 3).

The cover plate (3) is actually mounted idle on the motor shaft by means of a bush (8). Its angular position with respect to the shaft is given by a preloaded spring (9) which pushes the plate against a projecting part (10) of the shaft itself. During normal operation the cover plate and the motor shaft rotate as an integral part. This spring is dimensioned to avoid rotation and hammering of the cover plate under launch loads.
Whether a failure of the stepper or associated electronics should occur, the linear paraffin actuator (11) is energized and its rod extended. The rod pushes the shuttle (12) which engages the cover plate in a properly shaped surface, overcoming the spiral spring preload if necessary.

A mechanically actuated switch (13) gives the signal to discontinue power to the paraffin actuator at the required cover plate rotary stroke (about 90° from closed position, see fig. 3).
At any rate mechanical end stops are positioned in correspondance of the 0° (closed) and 94° positions.
At power off the actuator cools and retract by means of an internal reset spring, while the shuttle, latched by the security pin (14), keeps the cover open indefinitely. Although the instrument is degraded (the calibration function is lost) the cover has failed safe.

The main advantages of this emergency concept are:
- the very compact design (the emergency mechanism acts on the same axis of the primary mechanism)
- the absence of actuators or sensors positioned on the moving parts (minimization of the rotating mass, no electrical cables which have to undergo a rotation after a very long time exposure at very low temperature).

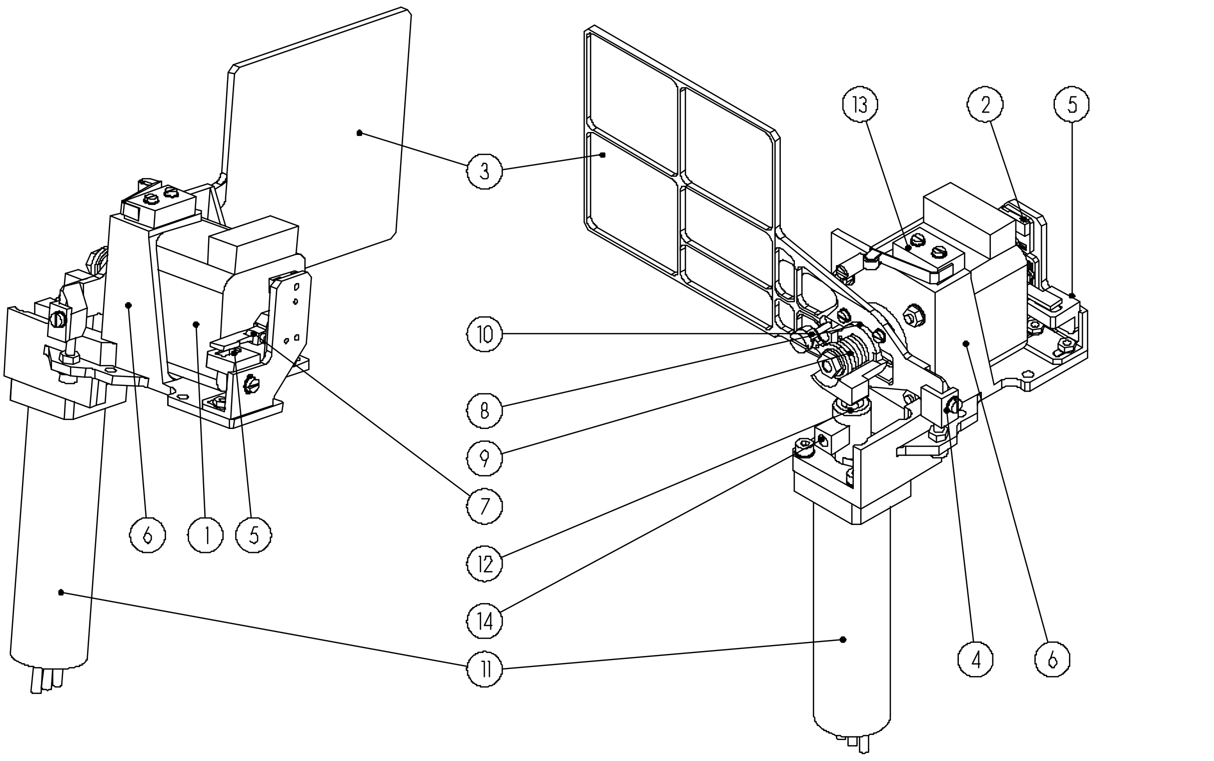

Fig. 1: VIRTIS-M Cover Mechanism

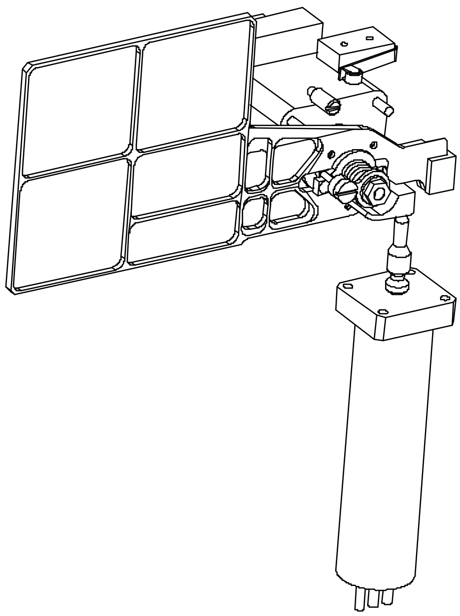

Fig. 2: VIRTIS-M Emergency Device (Non Actuated)

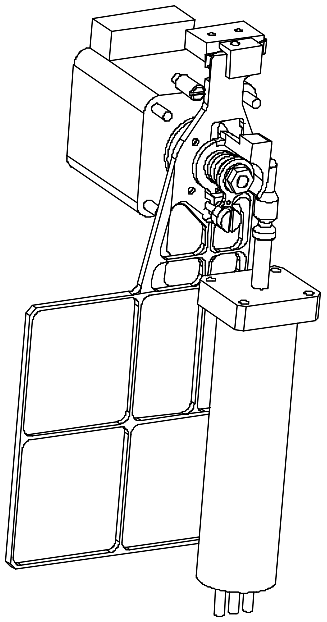

Fig. 3: VIRTIS-M Emergency Device (Actuated)

1.3 Design Criticalities

The critical aspects of the cover mechanism design are related to the cryogenic temperature and the long mission duration, including the deep space non operative phase.

Particular attention has been paid to the selection of materials and surface treatments in order to minimize fitting problems between parts having different thermal expansion coefficients and to avoid sticking / cold welding between contact elements. Furthermore the low temperature and the presence of optical components prevent to use wet lubricants.

In particular:

- the stepper motor lateral flanges and shaft have been changed from standard aluminium and steel, respectively, to titanium to comply with the thermal environment
- the soft preloaded ball bearings are provided with TiC coated balls (to avoid cold welding between races and balls) and with a Duroid cage for lubrication
- the shuttle material of the emergency device is an advanced polymer; a suitable clearance is foreseen between the shuttle itself and its aluminium seat
- the cover plate bush is made in titanium and is fitted on the motor shaft by interposing an intermediate liner in advanced polymer.

2. COVER MECHANISM FOR GIADA INSTRUMENT

2.1 Introduction

GIADA instrument (fig. 4) is foreseen to perform evaluations on the physical properties of the comet coma dust: its functionality is achieved by five *quartz MicroBalance Systems* (MBS), to measure dust mass fluxes, placed on the outer top plate and by a *Grain Detection System* (GDS) plus an *Impact Sensor* (IS), to measure dust momentum and speed, placed in the inner of the structure, receiving the particles from a 100 x 100 mm baffle, hosted on the outer top plate.

The top face of GIADA, actuated by a mechanism, acts as a protection cover for the internal sensors.

The cover has to be closed:

- at launch (also here, as in VIRTIS, a sealing is not required)
- during the non operative phases
- during short periods of the operative phases when the sun illuminates the GIADA cavity, to safeguard the internal sensors from overheating (the cover is provided with a MLI blanket)

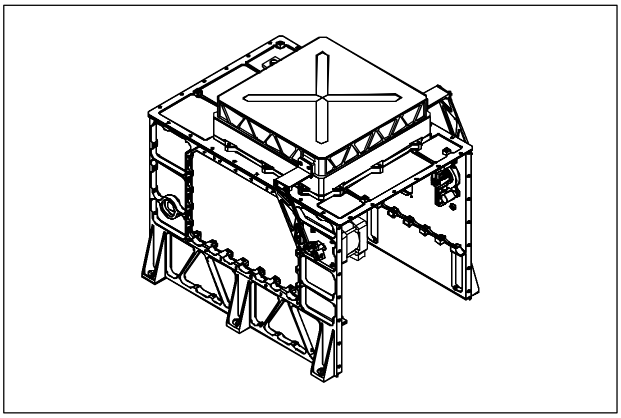

Fig. 4: GIADA Instrument

2.2 Cover mechanism

Referring to fig. 5, GIADA mechanism main elements are shown.

The cover (4) rotates around the axis of the stepper motor (1) by means of two arms. The driving arm (2), fitted on the motor front shaft, is supported by the motor internal bearings. The driven arm (3) is supported by an external radial bearing (5) whose seat is machined in the

instrument structure. This latter arm brings also the lever (6) to engage the mechanical end stops and the magnet (7) used to excite the Reed switches providing the cover status monitor.
As for VIRTIS the AISI 440C bearings have TiC coated balls to avoid cold welding phenomena and Duroid retainer as lubricant.

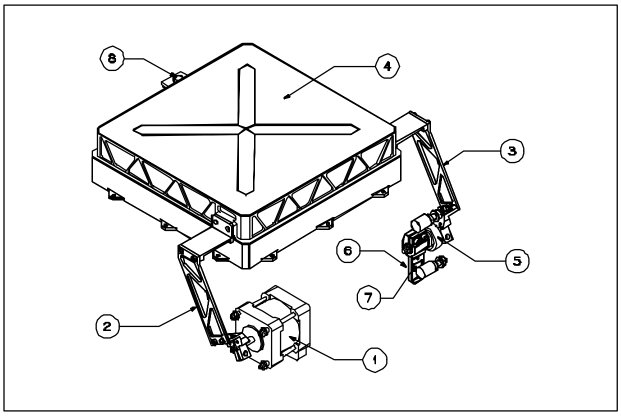

Fig. 5: GIADA Cover Mechanism

As it can be observed in the above figures, the mechanism architecture with the motor internal to the structure and the cover completely external brings to a non axial-symmetric and hence unbalanced mass distrubution. In particular the rotating elements have a mass of 170 grams and a Center of Mass (CoM) location about 120 mm far from the axis itself. This implies a noticeable inertia and, in 1g environment, a gravity generated torque acting in opposition or in accordance to the motor torque depending on the cover momentary position. As a consequence the cover arms are provided with a mechanical interface to mount a dedicated counterbalance to be used during ground testing.

Apart from ascent phase, where a launch lock is foreseen (see below), during the mission the cover is held in position by the motor detent torque. On the ground of the present analyses, this value seems to be sufficient to withstand the perturbation generated by Spacecraft maneuvers. As back-up solution, similarly to VIRTIS Covers, a magnet acting against a ferromagnetic element could be used to produce an additional retaining force (which of course the motor is able to overcome) in both extreme positions.

2.3 Launch Lock
The cover is kept in position during on ground transportation, vibration and launch by a locking system (fig. 6) based on a Frangibolt® (7). This element is composed by a fastener, joining cover and structure, coaxial to a Shape Memory Alloy (SMA) cylinder. When heated over its phase transition temperature this SMA cylinder improve its yeld strength and elongates to fracture the bolt, achieving the cover separation. After fracture the bolt head is secured in place by a wire.

This solution has the following advantages:
- a very compact design
- being a non explosive device, the actuator is almost shockless
- the cover is kept in close contact with the structure, minimizing the possibility of contamination of MBS and GDS elements during launch.

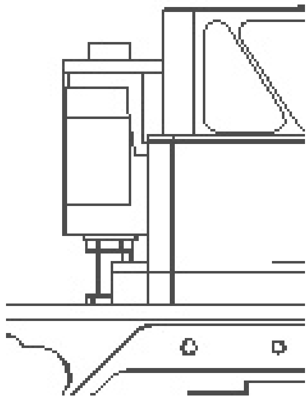

Fig. 6: GIADA Launch Lock

The actual contact between cover and fix structure happens only in a little zone around the fastener, external respect the functional elements protected zone.
Since the microbalances are very sensitive to the environment cleanliness, the following precaution has been foreseen to avoid at launch dust incoming this zone below the cover.
Cover and its rest counterpart are both provided with a 5 mm wide perimetral rim. These two rims are placed vis-a-vis, nominally 0.5 mm apart one respect to the other (see fig. 2.2-2) and protected by Kapton tape to avoid any metal to metal local contact.

The launch lock release will be performed during the commissioning phase. This release will allow the elongation of a spring plunger, placed close to the SMA actuator, producing a 2 mm lift of the most external cover point. This will leave only this point in contact with the structure for the rest of the mission, so limiting the risk of sticking to a very small area.

2.3 Design Criticalities
A critical point arises from the thermal gradient within the stepper motor, between rotor and stator. Due to the direct drive concept, the former is conductively linked to the cover arm (whose position is external to the MLI main blanket) while the latter is conductively linked to the structure. In between there are the ball bearings, well known to be low conductive elements.
During GIADA STM TV testing a gradient of about 50°C has been measured between the “cold” arm and the “warm” structure: herein the arm was protected with low emissivity tape only. This has demonstrated for the future models the need of protecting the arms with MLI, in order to limit this temperature gradient to a more acceptable value.

Another design aspect to be more deeply investigated is the limitation of the vibration loads at launch transmitted by the cover to the Frangibolt® and to the motor shaft in order to not overcome the load capacity of the fastener and of the ball bearings respectively.

3. NAVIGATION CAMERA COVER MECHANISM

3.1 Introduction

The Rosetta Navigation Camera Optical System performs both as *imaging camera* and *star sensor*. It switches from a function to the other by means of a refocusing system based on a rotary mechanism provided with three exchangeable optical elements to be placed alternately in front of the first lens of the camera telescope. Three different functions are required (see fig. 7):

- *defocused imaging, no attenuation (DNA):* the NavCam performs as *star sensor*
- *focused imaging with attenuation (FA):* the NavCam performs as *imaging camera* with reduced clear aperture
- *focused imaging, no attenuation (FNA):* normally used as cover, although the NavCam can perform as *imaging camera* with full clear aperture.

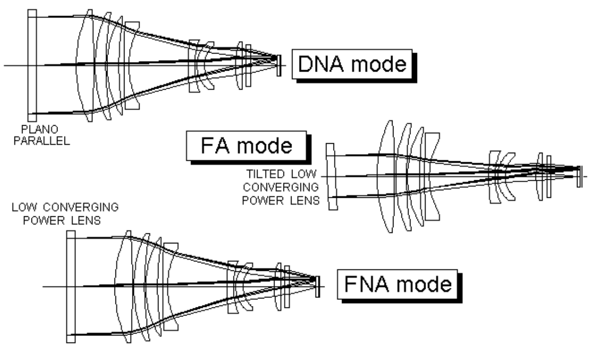

Fig. 7: NavCam modes

These elements must be positioned with an overall angular accuracy better than ± 20 arcmin (including misalignment / environmental effects) with respect to the camera optical axis.
In addition the rotary mechanism must guarantee protection of the NavCam internal parts against debris in all the working positions.
A minimum of 3000 in flight actuations are required.

3.2 Design Implementation

The Dust Cover and Attenuation Mechanism (in the following referred simply as cover mechanism) is supported by the external housing of the NavCam optical head, in front of the telescope (fig. 8).

The mechanism is composed essentially by an external aluminium/titanium structure (1), fixed to the NavCam box, on which a carrousel shell, a stepper motor, a bearings system and an encoder are mounted (refer to figg. 9, 10).

The carrousel shell (2) is composed by a frame in aluminium (for moving part lightening) carrying the three optical elements (3), fixed by a ring retainer, needed to switch the NavCam function. It is coupled to a shaft (4) made in titanium to match the bearings AISI 440C coefficient of thermal expansion.

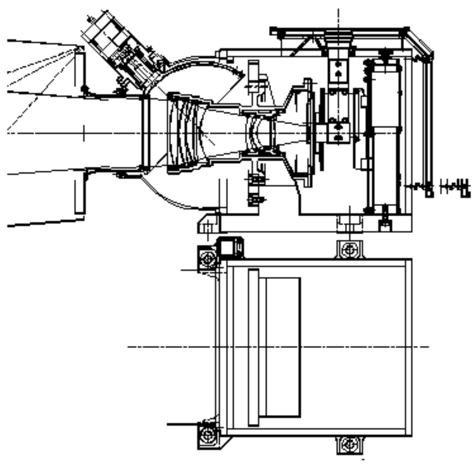

Fig. 8: NavCam Optical Head, cross section

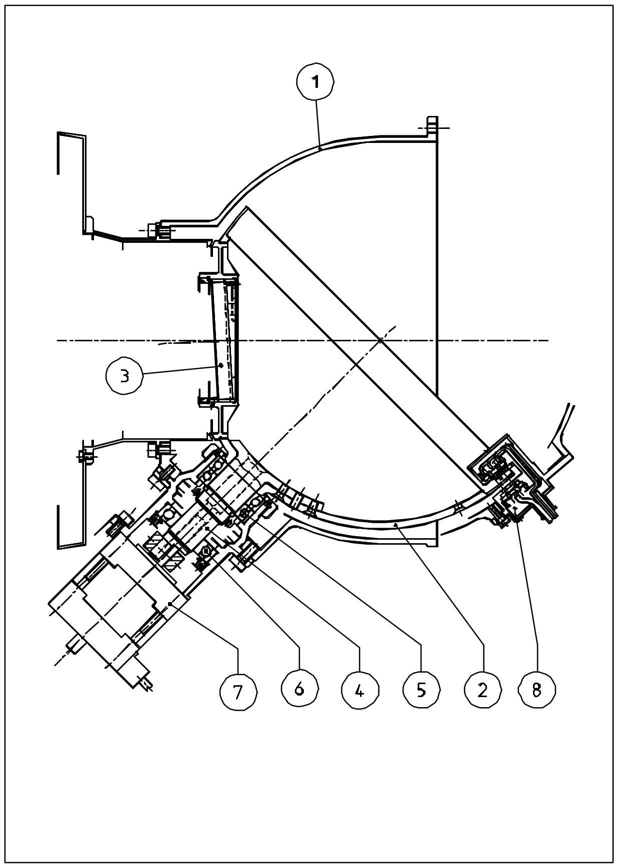

Fig.9: NavCam Cover Mechanism, cross section

The bearings system, housed in the titanium part of the external structure, is composed of two back to back hard preloaded angular contact shielded bearings (5) and a radial bearing (6) fitted on the titanium shaft. A similar application has been already successfully qualified for the Connector Mating/Demating Mechanism of the ERA CLU Program.
The angular bearings pair axial preload (100N) is a good compromise between the need to avoid the axial play during operational life of the mechanism and the torque increase due to thermal variations in the temperature range -25°C ÷ +55°C.

The bearings have 1/8” TiC coated balls and PTFE toroids. No lubricant is applied on the races.

The shell is radially balanced and has 360 degree free rotation. The rotating mass is about 600 grams, including the motor rotor, while the inertia is is $1*10^{-3}$ kgm^2. No launch lock is foreseen.
The entry of debris is minimized in whatever position by assuring a 0.8mm gap between the carrousel and the structure.

The framed stepper motor (7) is rigidly coupled to the rotating shell. As for the previously described mechanisms, the motor bearings have TiC coated balls and Duroid cage.

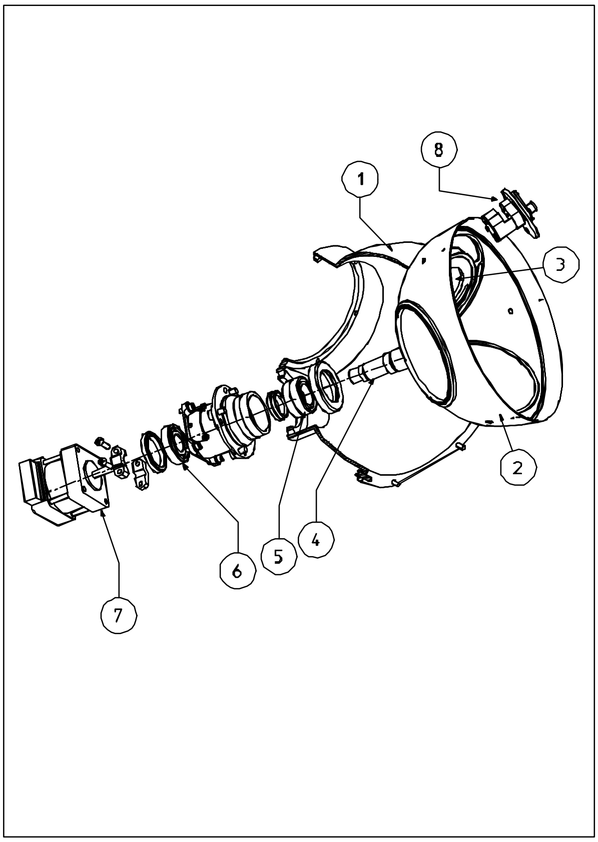

Fig. 10: NavCam Cover Mechanism, exploded view

The optical encoder (8), constituted by a pair of leds and photodiodes, is used to control the mechanism working position: in correspondence of one of the three mechanism lenses, two holes are present on the rotating shell so that when this lens is placed in front of the Camera optics, the two leds illuminate simultaneously both photodiodes (position “11”). Similarly, in correspondence of the second and third lens one hole is present in order to lighten only the first or the second photodiode (position “01” and “10” respectively).
On the other hand the initial alignment (performed under interferometer control), the mechanical stability of the mechanism structure and the motor accuracy are sufficient to guarantee the correct positioning in front of the Camera optics. The mechanism positioning error budget gives a total error of less than ± 7 arcmin with a factor 3 margin with respect to the required accuracy.

4. DEVELOPMENT STATUS

The Engineering Model of the VIRTIS Cover and the Breadboard Model of the NavCam Cover will be assembled and tested in the period September - November 1999. The verification will include functional/performance, environmental (vibration, TV) and life tests.
The GIADA Mechanism will be directly qualified on the instrument Qualification Model whose test campaign is planned within mid. 2000.

5. CONCLUSIONS

Since all of these mechanisms have apparently a similar purpose and are developed in parallel timeframes, an effort to have “common” design solutions should be expected.

Nevertheless as it can be noted from the above descriptions, the covers of the three instruments have to fullfil quite various functions, to comply with different environments and to take into account the general constraints of the Subsystem which they belong to.
As partial confirmation of the above, a real commonality has been achieved between the VIRTIS covers, where the functional and environmental requirements coincide. In this case more than 90% of the parts are the same (differences are only related to the cover plate and to the mechanical interface to the optical bench).

In general, the commonality among the mechanisms is limited to:

- the direct drive architecture between motor and load, with no gearing-down
- the stepper motor: it is basically the same although some minor differences are present in the windings (to comply with the system interfaces) and in the materials (for the VIRTIS covers, to withstand the cryo-environment). However these differences are not the cost driver for the motor
- the driving logic: the stepper is commanded in open loop while the position sensors are just used as status monitor, without feed-back on the reached position
- the lubrication of the motor bearings.

In conclusion it could be said that it was not easy as expected to standardize a space product, in particular when the designers are facing very specific requirements like those related to a scientific instrument like VIRTIS and GIADA and, in addition, they are affected by a bit of the typical healthy italian individualistic attitude.

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