CRYOSTAT COVER MECHANISM FOR THE HERSCHEL SATELLITE: DESIGN AND QUALIFICATION TEST RESULTS

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ABSTRACT

The Cryostat Cover Mechanism closes the Cryostat Vacuum Vessel on ground and is preventing air-leakage from outside and keeping high-vacuum inside the Cryostat of the European infrared space telescope HERSCHEL. The cover and its mechanisms are single point failure critical items for the entire mission and are designed for cryogenic operation.

Austrian Aerospace was contracted by EADS ASTRIUM and prime contractor ALCATEL to develop the Cryostat Cover Mechanism, which consists of the cover itself which features an active cooling loop, a deployment mechanism and a non-explosive hold-down- and release mechanism (see Figure 1). The main challenges are clearly the actuation temperature at 70 K, the required tightness on ground, and the high reliability of this device.

The QM has been successfully delivered in January 2005, the FM will be finally delivered by end of 2005.

The scope of this presentation is to present briefly the design of the Cryocover, and to highlight the qualification test results.

1. MAIN DESIGN FEATURES

Tightness of the Cryostat Cover to the Vacuum Vessel upper bulkhead plate is performed via an o-ring sealing, which is equally pre-loaded over its circumference. The needed force is applied via a pre-loaded lever. This lever is fixed on one end by 2 hinges and on the other end by the hold down & release mechanism. The lever is driven by torsion springs. To avoid sticking of the sealing to the Cryostat Vacuum Vessel after long closure time, 4 kick springs are equally distributed on the Cryostat Cover circumference. The hold down and release mechanism is spring actuated and uses a cryogenic non-explosive separation nut.

1.1 Special O-ring Sealing

The o-ring sealing is made from the fluorcarbon elastomer material Viton with a diameter of about 300mm. It is mounted to the Cryostat Cover via a high precision dove tail groove and tightens to the CVV upper bulkhead plate via a high precision flat surface I/F.

Before integration of the sealing a special vacuum bake out is performed. This is needed to remove short carbon-hydrogen chains from the Viton material, which would lead to sticking of the sealing to the metallic surface.

Directly besides the dove tail sealing groove a smaller second dove tail groove is used for fixation and support of support poles made of Vespel SP1. They get in contact with the CVV upper bulkhead plate after reaching a deformation of the Viton sealing of 20 %, thus preventing too high deformation of the sealing and metal to metal contact of the cover to the CVV upper bulkhead plate.

1.2 Cover

The cover is a light weight aluminum structure. It is equipped with the grooves for sealing and Vespel poles fixation in the lower area and an Ball Bearing I/F in the upper area.
It provides the mechanical I/F to the fixation devices of the thermally isolated cover heat shield. The cover has a conical shape with wall thickness 3 mm. The light weight design was possible only because the bending moments of the lower sealing area were eliminated as far as possible for all load cases by optimization of the location of the groove and flange design. The cover has also the I/F to the Johnston Couplings and an electrical connector. Tightening of these units is performed also via Viton o-ring seals.

1.3 Cover Heat Shield with Cooling Loop and Johnston Couplings

In order to limit parasitic heat load through the closed cover during ground operation the cover is equipped with a special heat shield in its lower area. It provides an effective emissivity of 0.01 at ambient temperature. This low value is reached by integration of 2 MLI packages between the cover upper structure and the heat shield.

The cover heat shield is equipped with an active nitrogen/helium cooling loop in order to achieve a temperature range from 25 K to 90 K. For connection of the nitrogen/helium supply the cover is equipped with special light weight Johnston Couplings, which stay mounted at flight. Disconnection of the nitrogen/helium supply lines is planned only a few days before flight.

The lower surface of the cover heat shield is machined to 2 special mirror shapes for calibration of the PACS and SPIRE instruments. The mirrors have to be of high precision and have an infrared emissivity requirement of 0.04 at 80 K within a small tolerance range. A special test program was performed to figure out the correct machining parameters for getting the required surface condition.
Figure 5—Cover heat shield mirrors

The cover heat shield as well as the cooling loop is manufactured from aluminum alloy with high thermal conductivity also at cryogenic temperatures in order to provide equal temperature distribution over the mirror surfaces. The Johnston Couplings are manufactured from stainless steel because they have to provide high thermal isolation capability. The I/F between the steel Johnston Couplings and the aluminum cooling loop is a welded connection with a special transition in between. An extended test program was performed on this welding process.

1.4 Preloaded Lever
The lever has the function of providing equal load distribution over the circumference of the cover sealing area. Therefore it is equipped with a ball joint as I/F to the cover (see Figure 2). The lever allows a pre load force of 10 kN.

1.5 Hinges / Torsion Springs
The hinges support the cover via the lever in closed configuration and provide a highly reliable (3x redundancy and avoiding metal to metal contact) and low friction bearing at the opening campaign. Hinge housing material is aluminum, shaft material is stainless steel.
For obtaining the opening torque 4 (redundant) torsion springs are used. Fixation of the springs is performed in a way to avoid load introduction into the bearings. This design provides a nearly frictionless spring support (see Figure 11).

1.6 Hold Down and Release Mechanism (HRM)
The HRM is designed as a three lever system to be compliant to the required kinematics. The motion of the connection lever in the area of the non explosive separation nut has to be a linear translation parallel to the release bolt axis, in order to avoid jamming of the bolt upon release.

Figure 6 – Hold down and release mechanism
The knee lever is equipped with a PTFE woven glassfibre liner on the I/F to the lever to avoid cold welding.

1.7 Non-Explosive Separation Nut
Supplier for the Non-Explosive separation nut was the company G&H.
Some modifications had to be performed on the commercial item, to provide fully compliance to the cryogenic temperatures. As a result of the first component level tests most non-metallic materials were removed, because they broke at the cryogenic temperature release and produced debris. The shape of the threaded segments was changed slightly to avoid singular load peaks at the release campaign.

1.8 Kick Springs
At the opening campaign during the first lift off the cover is mainly driven by the kick springs. There are 4 springs used, made from titanium alloy sheets. The pre load per kick spring at 70 K is 462 N.
The kick springs overcome potential sticking of the sealing on the metal surface of the CVV upper bulkhead plate.
Component level tests have shown that the ability of sticking is only given, when the sealing is not vacuum baked out. If vacuum bake out was performed no sticking effect could be realized also after closure and internal evacuation of 40 days. At the component level tests it was realized, that a sticking force could be measured only, if the opening campaign was very quick. The lower the opening speed, the lower was the
force and the force went to zero at an opening speed of 1 minute. This effect could not be realized at the functional opening test because of the high force of the 4 kick springs.

2. RESULTS OF THE COMPONENT LEVEL AND QUALIFICATION LEVEL TEST CAMPAIGN

2.1 Special O-ring Sealing

2.1.1 Component Level test over temperature range 70 K to 303 K

The sealing is not tight at cryogenic temperatures. Reason for that is, that the Fluor carbon material gets glass hard at cryogenic temperatures. For the test the arrangement was cooled down to cryogenic temperature and slowly heated up. At about 253 K (-20°C) the sealing gets back its elastomere structure and starts to tighten then.

2.1.2 Qualification Level test at room temperature

This test shows the helium tightness of the sealing. Helium tightness consists of the primary leakage (permeation through the sealing) and secondary leakage (gas stream around the sealing). The secondary leakage is available from start of helium exposure and as shown in the graph negligible. The primary leakage gets the max value after about 1 hour after saturation of the sealing with helium.

The used sealing with a length of about 300 mm provides helium leakage values of about 2.7E-6 mbar * l/sec. The measurement of Figure 9 was performed at the end of the qualification test program before delivery. After each closure of the cover a helium leakage test was performed, to verify, that no particular contamination on the sealing surface was available, which can increase the secondary leakage.

2.2 Cover Heat Shield with Cooling Loop and Johnston Couplings

The cooling loop and the Johnston Couplings belong to the most critical items of the project. Leaking or fracture, icing and clocking of these parts are mission critical and were put under special observation during the test phase. The leakage was measured before and after every test sequence. The specified leakage of 1*10^-9 mbar*1/sec could be reached without problems.
For thermal cycling tests performed on these items see par 2.10.3. The cooling loop and Johnston Coupling were proof pressure tested to 15 bar.

2.3 Preloaded Lever
At every closure sequence the lever deformation is measured. At the lever tip at the nominal pre load of 10 kN a deformation of 1.1 mm shall be measured.

2.4 Hinges / Torsion Springs
On component level a torque/friction measurement was performed at room temperature and at 60 K. The results were nearly equal. On equipment level torque and friction were measured only at room temperature.

2.5 Hold Down and Release Mechanism (HRM)
Component level tests were performed only at ambient, because no big influence due to temperature drop was expected.

Deformation measurement was performed for verification of the structural analysis result. An actuator spring torque/friction measurement was performed according to the test of par 2.4.

Opening time was measured with and without lever dummy. The opening time with lever dummy is 12 msec and without lever dummy it is 47 msec. This means that the max. HRM actuation energy comes from the lever pre load. Also the max. back lash of the knee lever was measured. For limitation of the back lash an aluminum deformation end stop was used.
The end stop must be changed after each release. During the equipment level tests the results of the component level tests were confirmed at room temperature and at 60 K.

2.6 Non-explosive Separation Nut

An extended component level test program was performed. This was necessary for qualification of the non-explosive device for the cryogenic temperature. For the test the separation nut was loaded very similar compared to the later use. Pre load over a way of some millimeters was provided by a package of Belleville washers. They simulate the deformation of the lever and hold down and release mechanism structural parts at the closure of the cover. After blocking of the system, the release bolt is tightened to the specified value.

The friction of the release bolt mounted to the non explosive separation nut was measured at each integration. So the friction coefficient, which was selected for the structural analysis was verified and the life time for the surface treatment of the release bolt and the threaded segments of the nut were determined. The threaded segments of the nut can be used over the specified life time of the nut of 8 releases. The release bolt shall be changed after every third release.

Before each cold release a vibration test at AAE test facilities at ambient temperature was performed.

After vibration a cool down to 60 K with liquid helium was performed. This was followed by evacuation and release. At each release the release time between application of fire current of 6 amps to release was measured. The measurement of the release was performed via a rupture wire. The release time was constant 40 ms.

After the 8th release the non-explosive separation nut was disassembled and a die penetration test was performed on all structural parts. No cracks or other defects could be found.

2.7 End Stops

The end stop force over deflection was tested on component level at room temperature and 60 K.
2.8 Kick Springs
No special test program for the kick springs was performed. The function was verified during the dynamic opening tests at room temperature and 60 K.

2.9 Equipment level vibration test

![Figure 17 – Vibration test arrangement](image)

The vibration test was performed mounted on a special vacuum cavity. So the tightness of the cover could be verified over the whole vibration test campaign.

2.10 Cryogenic qualification test program

2.10.1 Cryostat
For the cryogen qualification test program a new cryostat had to be designed and manufactured. The cryostat provides an inner usable diameter of 1200 mm and an inner usable height of 1600 mm. The Cryostat Cover was mounted at all tests with the cover rotation axis pointing in vertical direction. This was needed to achieve a zero-g environment for all opening sequences.

The cryostat is equipped with an outer nitrogen shell, which was used for pre cooling. The Cryostat Cover and all measurement equipment was mounted thermally isolated to the cryostat lid. So the whole preparation as well as the tests at room temperature were performed outside the cryostat in a clean room tent.

![Figure 19 – Cryostat lid with mounted Cryostat Cover](image)

2.10.2 Thermal cycling tests of the whole assembly
Eight thermal cycles between 303 K and 60 K was required and achieved at the test. Tolerances to lower temperatures at cooling and higher temperatures at heating were allowed to reduce effort on control systems.

With this test the cryogenic temperature in orbit phase is simulated.

![Figure 20 – Cryostat Cover thermal cycling test](image)

The leakage of the sealing, which got stiff and leaking at lower temperatures than -20° C was measured before and after this test. The leakage values were equal before and after the test and were lower than the required values.
2.10.3 Cooling loop thermal cycling test

Six thermal cycles of the cover heat shield were performed when the Cryostat Cover was mounted on the test vacuum vessel. This test simulated the ground test and storage phase with internal temperature of the Cryostat of 70 ± 10 K and external room temperature.

During this test it was verified, that the Johnston Coupling and the cover itself were isolated as well that no condensation or icing occurred.

Connection/disconnection tests of the Supply Lines were performed verifying that no icing and clogging of the cooling loop can happen. Therefore the male parts of the Johnston Couplings on the cover are equipped with non return valves, which provide high tightness after de-coupling. So it can be avoided that humid gas streams into the cooling loop also at internal under-pressure.

The supply lines are equipped with overpressure valves to avoid overpressure in closed volumes. Only the cooling loop itself does not provide an overpressure valve. Overpressure of the cooling loop is avoided by the instruction, that disconnection of the supply lines is allowed at a cover heat shield (and supply line) temperature higher than 150 °C, which is always given except during and directly after cooling.

At this test, the cover is kept at 20 °C with cooled down cover heat shield to 4 K. So the function of the iso-static mounts and the thermal isolation was also verified at this test.

Thermal stress occurred also on the cooling loop and Johnston Couplings with a high temperature gradient and the material selection of stainless steel for the Johnston Couplings and aluminum for the cooling loop.

Part of this test was also the verification of the temperature uniformity over the cover heat shield of required ±2 K at 80 K which could be achieved by the use of a special aluminum alloy.

2.10.4 Dynamic opening tests at 60 K

On qualification level 5 cover opening tests were performed.

The cover was closed i.a.w. procedure, vibration tested, 8x thermal cycled between 303 K and 60 K and opened via electrical release at 60 K.

After the first opening sequence only the non explosive separation nut was vibration tested and instead of thermal cycling only cooling down to 60 K was performed.

The cover opened 5 times w/o any problem. A lot of parameters were measured like release time of the non-explosive separation nut under varying current, opening time, force on the end stop springs, actuation of the limit switches for closed cover and for open
cover. The results were fully compliant with the analysed values and the results of the component level tests.

3. CONCLUSION

The qualification program was finished successfully and the hardware was delivered for further qualification tests on system level.

Also the acceptance program for the proto-flight model is nearly finished. The hardware is presently used by the customer for closure of the cryostat and for instrument calibration. It will be returned to AAE by end of the year for the thermal cycling test and for one cryogen release before final delivery.

4. LESSONS LEARNED

4.1 Cryogenic knowledge for hardware development

Although AAE is supplier for cryogenic thermal hardware with excellent reputation some additional knowledge concerning material selection and material parameters for cryogenic application had to be investigated during the preliminary phase of the project.

4.2 Establishment and conductance of a cryogenic test program

Support for the preparation and conductance of the cryogenic tests could be achieved by a partnership with the Technical University of Vienna. Special skills for cryogenic testing especially measurement under cryogenic conditions, control of parameters and safety aspects could be gained.

4.3 Knowledge on spring actuated mechanisms

During the preliminary phase the concept of the spring actuated mechanisms could be improved further and is already used at other projects for deployment units. The design for nearly friction free deployment allows selection of actuators with lower pre tension. So high margin of safety against structural failure can be achieved.

4.4 The non-explosive separation modification and qualification

The non-explosive separation nut, which had to be modified for cryogenic use could be made cryogenic compatible after application of 6 changes. After incorporation of the new features the reliability was proven by successful performance of the component level and equipment level test program.

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