DEVELOPMENT OF A TWO HINGE SHUTTER AND CALIBRATION MECHANISM

Matthias Schmalbach [(1)], Max Eigenmann [(1)], Tilo Schmidt [(2)]

[(1)]RUAG Space, Schaffhauserstrasse 580, CH-8052 Zürich, Switzerland, Email: Matthias.Schmalbach@ruag.com, Max.Eigenmann@ruag.com
[(2)]HTS GmbH, Am Glaswerk 6, D-01640 Coswig, Germany, Email: Tilo.Schmidt@htsdd.de

ABSTRACT

Shutter mechanisms are typical for scientific optical instruments. Independent from the specific mission requirements typical design drivers are the repeatability and reliability, cleanliness, light tightness of the hinges, thermal distortion and the redundancy and fail safe concept. All these items have been solved in the frame of the EnMAP Full Aperture Diffuser (FAD) development, a cooperation project with HTS Coswig.
The mechanism consists of a Spectralon diffuser plate which is suspended in an aluminium hatch frame designed to keep thermal stresses and distortion to a minimum. The hatch is mounted on a titan pivot and can be moved by a brushless DC motor with a planetary gear head. In case of failure the special coupler and a preloaded spring allow removing the hatch and the frame out of the light path. A second hatch which is directly driven by an identical actuator protects the diffuser plate from sunlight in the stored position. This becomes necessary since the Spectralon is very sensitive to degradation under sunlight. Frangibolt release systems from Tini-Aerospace are used for locking the hatches during launch and for the fail safe mechanism. Further the mechanism has baffles on the back of the hatches and the walls wherever possible. The mechanism is equipped with potentiometers for the angular position of each hatch, end position and release sensors as well as emergency heaters and temperature sensors.
This paper presents the special features of the developed mechanism: the thermal suspension of the Spectralon plate, the fail safe mechanism of the hinge as well as the fail safe separation mechanism between the actuator and the potentiometer.

1. INTRODUCTION

EnMAP[(*)] (Environmental Mapping and Analysis Program) is a German hyper spectral satellite mission providing high quality hyper spectral image data on a timely and frequent basis.
The main instrument on board is the hyper spectral imager (HSI) with two separated spectral channels in the VNIR and SWIR spectral range. Both spectrometers are designed as prism spectrometers and share a common telescope with a field splitter in the telescope focal plane.

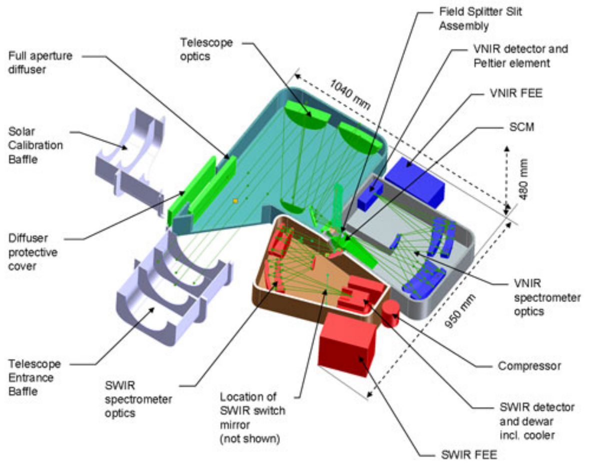

Figure 1. HSI Instrument Overview (www.enmap.com).

The Full Aperture Diffuser at the telescope entrance is a typical shutter and calibration mechanism. This unit consists of the telescope entrance baffles, the sun diffuser for calibration of the Instrument and the diffuser protective cover.

2. DESIGN OVERVIEW

The general design of the mechanism is shown in Figure 2 below. The mechanism has an overall envelope of 660mm x 480mm x 500mm and a total weight of 19kg without MLI.

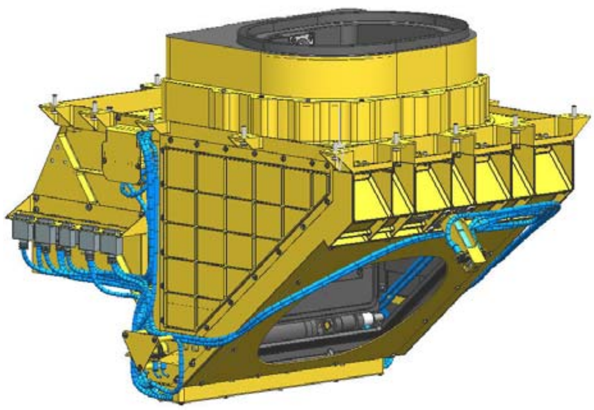

Figure 2. CAD view of the Mechanism.

The mission requirements are based on the three different operation modes for the mechanism.

[(*)] Das EnMAP Projekt wird im Auftrag der Raumfahrtagentur des Deutschen Zentrums für Luft- und Raumfahrt e.V. (DLR) mit Mitteln des Bundesministerium für Wirtschaft und Technologie unter dem Kennzeichen 50 EP 0801 geführt.

1. Launch mode, when the diffuser hatch and diffuser protection hatch close and seal all optical light paths to the telescope and provide protection against contamination.
2. Earth observation mode, when light from the Earth can enter the telescope and the diffuser panel is stored.
3. Sun calibration mode, when the Earth light path is closed and the light path for sun calibration is open.

During operation in space, the FAD mechanism controls two different light paths at the entrance of the telescope exposed to the direct space environment. Both light paths have to be separated (light tightness). In addition an optical element (optical diffuser) needs to be placed in the optical path in sun calibration mode very accurately. For this reason the sun calibration light path heading must be in alignment with the system level optics. This is achieved by alignment of the Spectralon plate during assembly and integration at RUAG Space within ± 5 arcmin (0.08deg) angular cone and a repeatability of < ± 1 arcmin (0.017deg). Further alignment during S/C integration is given with the specially designed I/F.

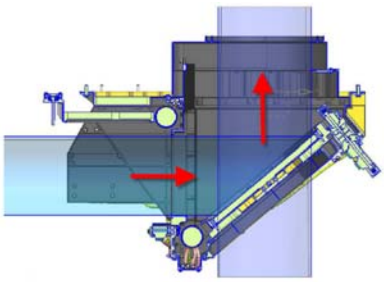

Figure 3. Cutaway view of the mechanism (Sun calibration mode)

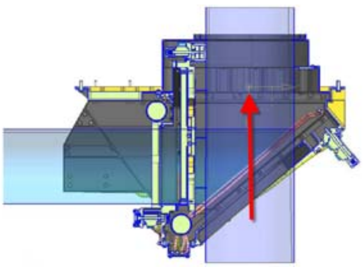

Figure 4. Cutaway view of the mechanism (Earth observation mode)

The Spectralon diffuser plate is located in an aluminium hatch frame. This hatch is mounted on a titanium pivot and can be moved by a brushless DC motor with a planetary gear head.

In case of failure the special coupler and a preloaded spring allow removing the hatch and the frame out of the light path. A second hatch which is directly driven by an identical actuator protects the diffuser plate from sunlight in the stored position. This is required in order to protect the Spectralon material from the degradation effects of sunlight.

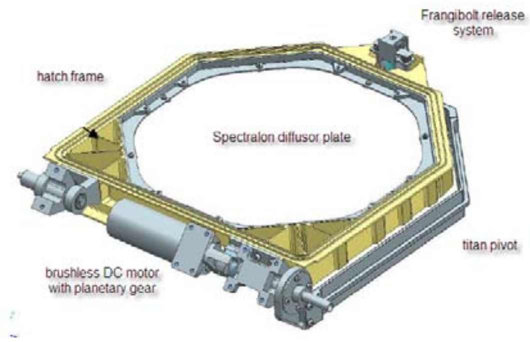

Figure 5. CAD view of the sun diffuser hatch (SDH)

Frangibolt release systems from Tini Aerospace are used for locking the hatches during launch and for the fail safe mechanism. Further the mechanism has baffles on the back of the hatches and the walls wherever possible. An inner baffle defines the interface to the instrument telescope system. The mechanism is equipped with potentiometers for the angular position of each hatch, end position and release sensors as well as emergency heaters and temperature sensors.

3. KEY REQUIREMENTS

Independent from the specific mission requirements typical design drivers for Shutter mechanisms in scientific optical instruments are the repeatability and reliability, light tightness of the hinges, thermal distortion and the redundancy and fail safe concept.

3.1. Repeatability and Reliability

Exact position of the Spectralon plate in closed position is of critical importance for the instruments measurement results. After each open and close cycle, this position has to be reached within a tolerance of < ± 1 arcmin (0.017deg). This has been ensured by implementing an advanced tolerance, tolerance control and adjustment concept. In addition to the tolerance concept, an adjustable sensor system has been developed, detecting the end stop of the hatches in closed and open position with precise micro switches (repeatability < ± 0.001mm) as well as the intermediate positions of the hatches with potentiometers.

3.2. Light Tightness of the Hinges

Labyrinth seals are used for the light tightness of the mechanism in the operation and the calibration configuration.

For the operation configuration it is important that no stray light enters the telescope baffle from the sun port. In this configuration the SDH is open and the DPH is closed to protect the Spectralon plate. The DPH is designed with a single fin labyrinth and the SDH with a double fin labyrinth on the top and bottom side. A sketch of the SDH labyrinth is shown in Fig. 6. The red line is a possible worst case light beam. As can be seen it has to be reflected several times to pass through the labyrinth.

(*) Das EnMAP Projekt wird im Auftrag der Raumfahrtagentur des Deutschen Zentrums für Luft- und Raumfahrt e.V. (DLR) mit Mitteln des Bundesministerium für Wirtschaft und Technologie unter dem Kennzeichen 50 EP 0801 geführt.

For the DPH the light flux reduction is lower because of the single fin labyrinth. This reduction represents the protection of the SDH Spectralon plate and is in addition to the SDH seal tightness used for the operation configuration.

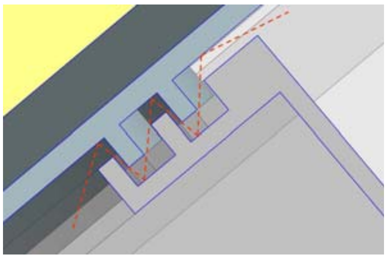

Figure 6.Typical Labyrinth System

3.3. Redundancy and Fail Safe Concept

The most critical part in the mechanism is the SDH. A malfunctioning of the SDH hatch in its closed position would lead to a total loss of the instrument and therefore the mission goals.
Apart from structural elements all components of the SDH are implemented in a redundant version. The actuator has redundant windings and hall sensors. The mechanism uses redundant slide bearings for the hatches. These can withstand high mechanical loads and work without liquid lubrication which makes them more reliable than ball bearings.
The launch lock mechanism of the SDH is mechanically redundant and also built with redundant heaters. All sensors are also fully redundant.
Further a fail safe mechanism (FSM) is implemented which can overcome the nominal SDH operations under all configurations and positions. The FSM spring moves the hatch and the guiding arm of the SDH into stored conditions.
If the FSM is used or the DPH is breaking down the calibration option gets lost, but the telescope is still functional.

4. DETAILED DESIGN SOLUTIONS

In the frame of the mechanism development process, several detailed design solutions have been created and analysed. Some of them, most likely to be useful for other mechanisms, will be explained in the following chapters.

4.1. Thermal Suspension of the Spectralon Plate

The Spectralon plate is the most sensitive part of the mechanism. As it is used for calibration purposes it is important that its optical properties remain as constant as possible throughout the mission duration. Several sources which may modify the optical properties have been addressed in the design of the FAD mechanism : Handling jigs for assembly and integration, easy replacement of the Spectralon even after integration on the S/C as well the attachment of the Spectralon to the hatch are the most important design aspects which are considered. Shortly before flight, the proto flight grade Spectralon plate used for acceptance test, will be replaced by a flight model.

The front surface of the Spectralon plate is mounted on a metallic frame with eight standoffs which are tightened to the Spectralon main frame (see Fig. 5).
Sufficient large clearances between the frame, the Spectralon plate and the fixation standoffs can compensate different thermal expansions. The standoff design allows a defined torque for the fixation on the frame in order not to over compress and damage the Spectralon. On the bottom side an o-ring gasket is used to compensate thickness tolerances of the Spectralon and ensure a clamping force which does not vary significantly (see Fig. 7). In addition the clamping force is independent from the fixation torque of the corresponding bolts.

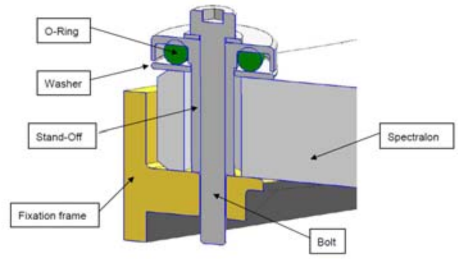

Figure 7. Sectional view of Spectralon plate fixation

The described fixation points with the o-rings only press the Spectralon plate against the frame. They do not fix it in the plane of the SDH. This is realised by guiding slots in the Spectralon plate with corresponding brackets in the frame (see Fig. 8). The reason for this type of suspension is the sensitivity of the Spectralon which may buckle due to thermal loads and hence change the optical properties.

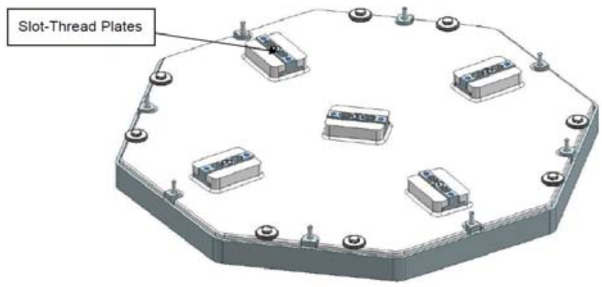

Figure 8. Spectralon Mounting Plate.

For stiffness reasons the Spectralon is additionally fixed in the centre region via slot thread parts to the SDH. All fixation elements are aligned such that their working lines meet in one point. This allows the Spectralon plate to expand star-like (see Fig. 8) in all directions avoiding bucking of the Spectralon.
Detailed analysis demonstrated that potential deformations of the Spectralon plate originating from thermal effects and machining tolerances respectively are kept to a minimum with this design.

(*) Das EnMAP Projekt wird im Auftrag der Raumfahrtagentur des Deutschen Zentrums für Luft- und Raumfahrt e.V. (DLR) mit Mitteln des Bundesministerium für Wirtschaft und Technologie unter dem Kennzeichen 50 EP 0801 geführt.

4.2. The Fail Safe Mechanism

The fail safe mechanism (FSM) is used to move the SDH and the drive arm out of the instrument light path in case an error occurs. Such an error could be a malfunctioning of the actuator the Launch Lock Mechanism (LLM) or any other part in the nominal drive chain.
For the FSM a preloaded torsion spring is integrated between the drive arm and the SDH. In nominal operation the drive arm is connected to the SDH with a Frangibolt release system. If the Frangibolt is released the spring moves the hatch into the stored position and the drive arm into the launch configuration. In this way all parts are out of the instrument light path.

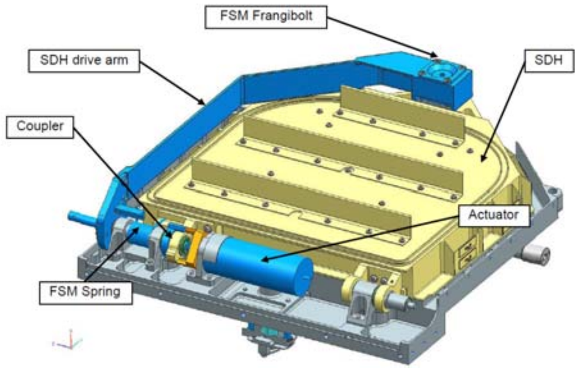

Figure 9.The Fail Safe Mechanism (FSM).

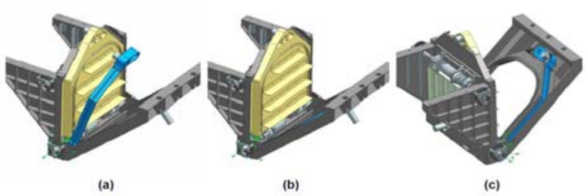

Figure 10.FSM Release Sequence.

Fig. 11 shows the coupler in the different steps during the release sequence of the FSM from the nominal to the released configuration. The motor part of the coupler is connected to the hatch and arm in picture (a), arm and hatch are separated in picture (b) and (c) and therefore the motor is disconnected.

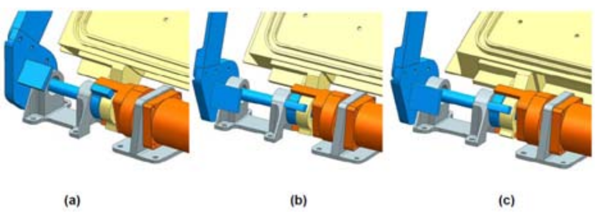

Figure 11.FSM Release Sequence.

4.3. The Fail Safe Separation Mechanism

To be able to track the position of the hatch a potentiometer has been used.

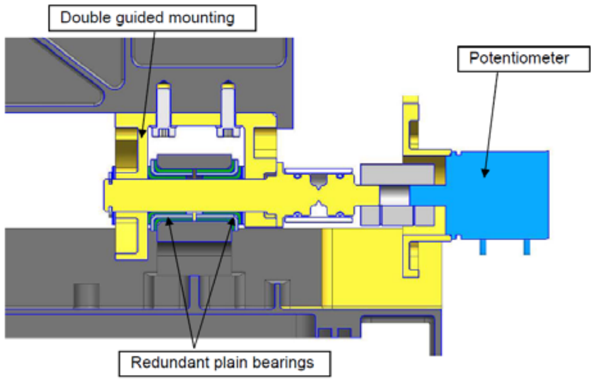

Figure 12. Separation Mechanism.

The potentiometer is fixed to the rotation axes via a flexible coupling which compensates small angular misalignments. In line with the flexible coupling a rated breaking point is placed on the shaft for the case of the potentiometer getting blocked. Potential debris from the cracked shaft is collected in a cylindrical shaped container which is sealed towards the rotating shaft via PTFE o-rings.

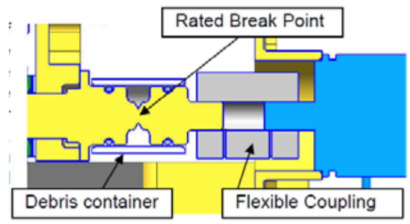

Figure 13.Rated Breaking Point of Potentiometer Axis

Component tests have verified the adequate function as well as the breaking point of the axis already.

5. FAD PERFORMANCE

The FAD will be subject to a qualification test program. The test program will demonstrate compliance to the following parameters:

Parameter	*Value*
Operational Temp.	-40°C to +60°C
Non-Operational Temp.	-50°C to +80°C
Total Hatch Open/Close Cycles (incl. ECSS Factors)	860
Max Actuator Power Consumption (duration)	4.3W (25s)
Max Frangibolt Power Consumption (duration)	49W (max. 70s)
Max. Heater Power Consumption (duration)	2.5 W (as required)
Opening and Closing Speed of Hatches	3.6°/s

6. NOTES

This paper will be presented at the poster session of ESMATS 2011 in Constance.

(*) Das EnMAP Projekt wird im Auftrag der Raumfahrtagentur des Deutschen Zentrums für Luft- und Raumfahrt e.V. (DLR) mit Mitteln des Bundesministerium für Wirtschaft und Technologie unter dem Kennzeichen 50 EP 0801 geführt.