DESIGN, QUALIFICATION AND LESSONS LEARNED OF SWIR SWITCH MECHANISM FOR ENMAP MISSION

K. Zajac, J. Richter, T. Schmidt, S. Müller, A. Bergander, K. Seifart
HTS GmbH, Am Glaswerk 6, 01640 Coswig, Germany

Abstract

The SWIR Switch Mirror (SSM) Assembly is one of three mechanisms which are developed by HTS for the EnMAP space segment in subcontract to OHB System AG Munich. EnMAP is the Environmental Mapping and Analysis Program of the German Space Agency DLR. The SSM is integrated into the Instrument Optical Unit (IOU) in front of SWIR detectors and allows switching between nominal and redundant position. This paper summarizes the main functions and design features of the Hardware and focuses on qualification testing which has finished successfully in 2014. In addition to standard test campaign required for qualification model (QM) also a shock emission measurement of the release mechanism activation was conducted. Test conduction and results will be presented with focus on deviations from the expected behavior, mitigation measures and on lessons learned.

1. INTRODUCTION

The SWIR (Short Wave Infrared) Switch Mirror (SSM) assembly, developed by HTS in subcontract to OHB System AG Munich, which is part of the Hyper Spectral Imager of the Environmental Mapping and Analysis Program (EnMAP) space segment, is integrated into the Instrument Optical Unit (IOU) in front of SWIR detectors. The SSM allows 45 degree switching of a mirror between nominal and redundant position. In nominal position the mirror is outside of the light path and the optical beam passes to the nominal detector. Only in case of malfunction of the nominal detector the mirror is installed into the light path and directs the beam towards the redundant detector.

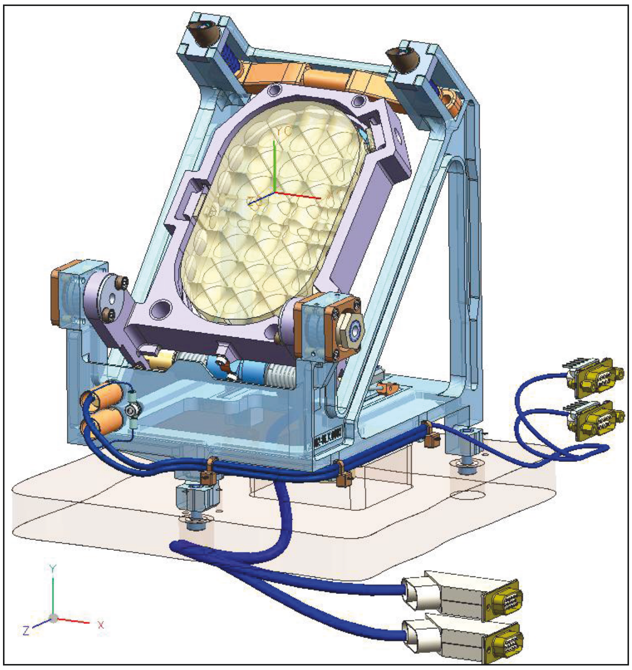

FIGURE 1. SSM assembly in operational position

The SSM consists of an aluminum structure providing necessary mechanical interfaces and supporting and carrying the actuator assembly with the OHB System AG supplied switch mirror, including sensors for release verification. After unlocking the release mechanism by actuating a Frangibolt actuator the switch mirror rotates 45° until the operational position is reached. The position is defined by a 3-point-arrangement and locked by preloaded torsion springs. The end stop is designed to allow for elastic overshooting to reduce shock and deceleration loads. Final position is accurately defined by precisely manufactured surfaces for providing the required positioning accuracy. Springs for actuation were used because only one release of the mirror is required and a return to nominal position is not necessary (in orbit). For tests on ground the nominal position can be reached by refurbishment measures. The design of the SSM is shown in Figure 1 in operational position including nominal and redundant harness for sensors and actuator.

2. REQUIREMENTS AND APPROACH

2.1. General Requirements

Table 1 comprises a selection of requirements which have driven the development and verification effort of the mechanism.

Requirement	Quantity
Movement of Mirror	45°
Accuracy of operational (actuated) position	± 10 arc min
Mirror stability in operational (actuated) position	± 1 arc min
Operational temperature range	0°C / 40°C
Non-operational temperature range	-40°C / 80°C

TAB 1. Requirements for SSM

2.2. Functional Requirements

The main functional requirement of the SSM is to fold the light path into redundant detector direction. To comply with this, not only the exact position of the folded mirror is essential, but also the exclusion of any residual stresses on the mirror which might impair the optical quality of the reflection. The features that were introduced to prevent this are a stress decoupling bonding design of the mirror to the frame and a spring motorized separate frame that prevents bending loads on the mirror frame.

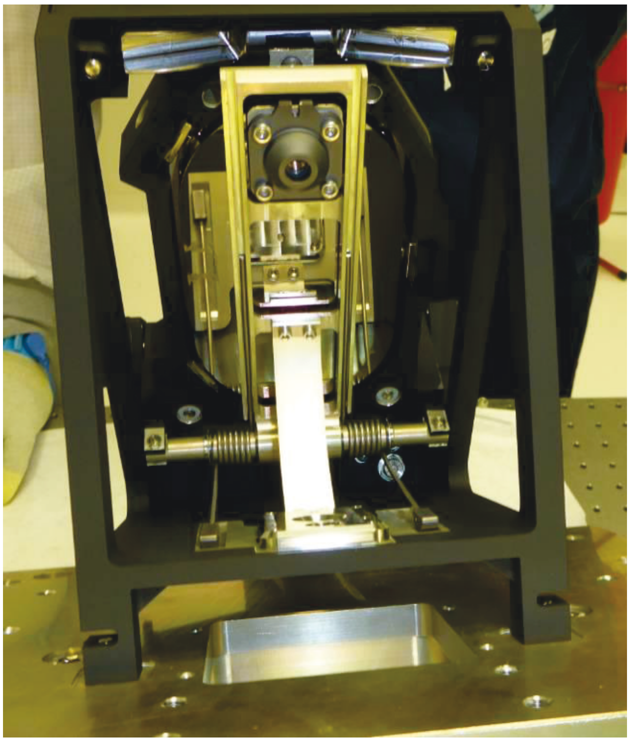

FIGURE 2. Motorization frame below the mirror frame

3. INTEGRATION

The assembly and integration of the SSM qualification model (QM) was performed inside the HTS ISO 6 clean room. All steps were noted in the as-run assembly and integration procedures starting with the mirror support and integrated mirror. As the mirror I/F, design and manufacturing was under responsibility of OHB, the bonding of mirror and mirror support was also performed by OHB AIT. All three mounting points consist of flexure hinges on both sides of the connection. Flexure hinges are integral part of the design and use the elastic properties of the material. The resulting configuration status of the SSM QM hardware was documented in the as built configuration list. All non conformances which appeared during integration were handled by non conformance reports and boards. Each applicable performance step of the SSM hardware is recorded at the log card of the mechanism. The particular and molecular contaminations were monitored by witness samples. The numbers of the used witness samples were noted and evaluated within the contamination budget report.

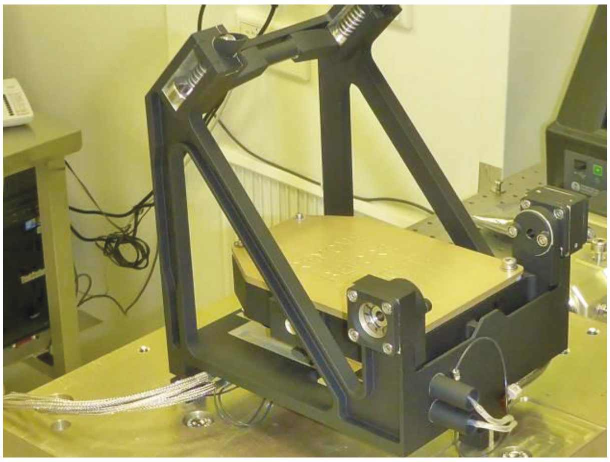

FIGURE 3. SSM QM after final assembly with mirror protection cover

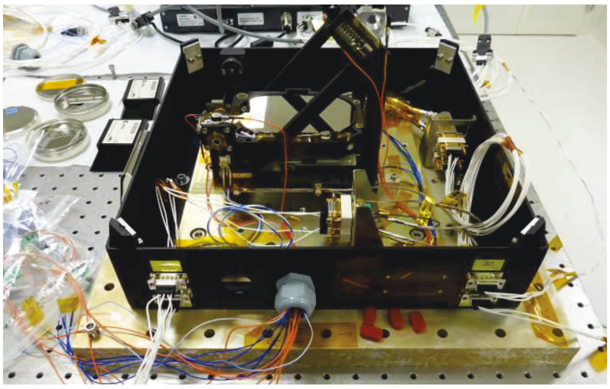

FIGURE 4. SSM QM assembly on interface plate with integrated sensors inside frame with mounting plate

4. TEST

The qualification test campaign started with performance testing focused on verifying the functionality and accuracy of the SSM assembly. A protective test frame was used allowing for operation under different spatial orientations. Also the procedures for refurbishing the Frangibolt® Actuator were checked.

FIGURE 5. CAD view of the protective frame assembly with triangulation sensor for repeatability measurement

4.1. Functional Test

After successfully performing the physical properties tests with mass, mechanical interface and electrical parameter measurement, the functional tests consisting of light path obstruction check, light path switch function test and position accuracy / repeatability test were performed.

Throughout all functional tests and also for life testing the SSM was mounted on its adapter plate, and this plate remained mounted in the protective frame assembly (see Figure 5). The frame allows orienting the SSM wrt. the gravity vector for tests on the SSM actuator and for frangibolt refurbishment. For position measurements, a laser displacement sensor was mounted on a supporting structure, which allows tilting the used laser sensor by 45° and having precise end stops defining the sensor's position.

The light path switch function has been tested with the mirror support being released at an angle of 45° under maximum gravity condition. Upon activation of the Frangibolt heater circuit and the resulting release, the mirror reached the end stop and the release switch changed its state to "released" as expected.

The SSM light path switch angle and the repeatability of the mirror position are measured using a laser triangulation sensor. For the repeatability measurements of the mirror, the sensor points directly on the mirror. For the measurement of the switch angle, the sensor is tilted about the same angle and in the same direction as the mirror, the sensor tilt angle having been precisely adjusted to 45° using a goniometer and micrometer screw before the measurement. The sensor is arranged on a linear positioning stage, which allows creating relative motion between the sensor and the mirror and reference surfaces. With this arrangement, a line measurement is possible in addition to simple point measurements, allowing to determine the mirror angle.

The error on this position measurement is determined by the goniometer used to adjust the tilt angle, which limits the accuracy and resolution of the measurement to 0.05°. For repeatability measurements however, the triangulation sensor and the length of the 'scan' line limit the accuracy. Repeatability on the same position, such as after multiple deployments, can be measured with about 5 arc sec accuracy.

4.2. Vibration and Shock Test

The sine, random vibration and shock tests were performed at Astro- and Feinwerktechnik (AFW) test facility, see Figure 6 for the setup. 16 channels were available for measurement. Six of them were used for the pilot sensors, the remaining ten channels for measurement of responses at dedicated locations of the mechanism. The applied sensors, especially the triaxial sensor on the mirror upper side and the pilot sensors are selected such that they also can be used for shock testing of the mechanism as. The vibration test was done axis by axis in the sequence sine sweep, sine vibration, random vibration, sine sweep. During sweep the natural frequencies were determined and compared to test prediction values.

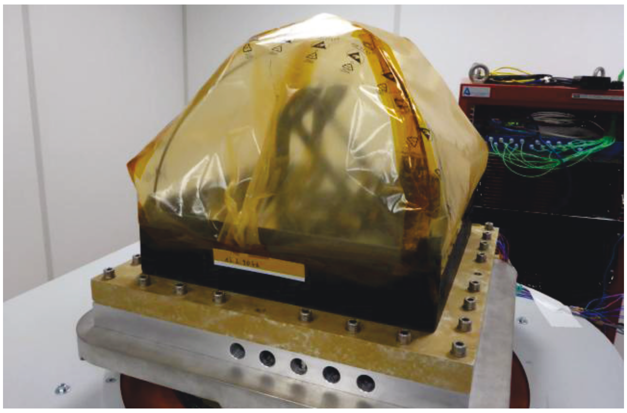

FIGURE 6. The SSM mounted on its support plate with a protective frame and cover on the shaker, arrangement for testing in y-direction

Shock test was executed on a ringing table. The excitation was performed by action of a shock hammer at a defined location and with a defined intensity. The selection of the hammer mass, of the location, and of intensity was determined by pre-tests using a dummy of the mechanism. The test program included an additional shock emission recording while activation of the Frangi actuator and the successive breaking of the Frangibolt. The mechanism was fixed on the ringing table in such a way that the release direction of the breaking bolt is perpendicular to the mounting plane.

4.3. Thermal Test

The thermal vacuum test is simulating the thermal and pressure environment applicable to the SSM. The thermal vacuum cycling was performed at DLR Institute for Optical Sensor Systems, Berlin, see Figure 7 for the setup. The temperature of the TV chamber was monitored with thermal RTD PT100 sensor at the defined mechanism thermal reference point. The general conditions of the thermal vacuum cycling test are a pressure less than 10^{-4} mbar, maximum temperature gradient dT/dt of 2 K/min and dwell time of minimum 2 hours. For qualification the temperature regime consists of one cycle starting at room temperature (RT) then rise to +70°C and drop to -30°C followed by 7 cycles +50°C to -10°C. Before returning to RT a hot plateau at 80°C is applied to bake out volatile constituents.

One point to mention concerns the release by the Frangibolt® actuator. The principle is breaking a bolt with a rated break point by expansion of a shape memory alloy. The maximum operation temperature (meaning save of unintended release) of the actuator given in the datasheet is +80°C. During functional testing earlier in the test campaign, the release temperatures were monitored with the actuator internal sensor and varied in the range from +72°C to +105°C. This had consequences for the thermal testing which was planned to verify the non-operational temperature of +80°C. A revisit of the thermal requirements by the customer allowed for reduction of the maximum non-operational temperature to +60°C. However the resulting qualification temperature of +70°C was still critical in terms of unintended release and any overshooting in the temperature control had to be prevented.

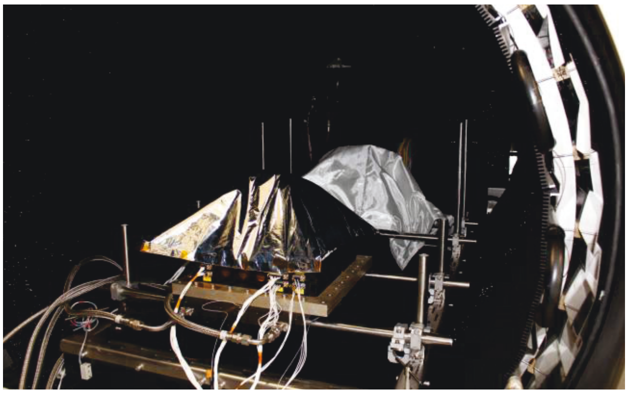

FIGURE 7. SSM together with a second system prepared for testing in the thermal vacuum chamber

4.4. Life Time Test

The test was focused on achieving a total number of 50 mirror deployments while maintaining the required accuracy of the deployed position. The life time test of the SSM was conducted with 4 releases by the frangibolt actuator, 45 manual releases followed by another refurbishment and frangibolt actuator release. The high reliability of the Frangibolt release system allows performing the majority of the actuations with a release hook and concentrating on motorization and general observation of the deployment process.

5. RESULTS

The mechanism reached its 45° position after all manually or EGSE triggered actuator releases in all tests without failure and successfully passed the vibration and thermal testing campaign successfully. In some cases however, during manual release, a delay of between 10 and 30 seconds of the folding after triggering was observed. This was first suspected to be due to a detrimental friction condition of the spring lever sliding piece on the Alodine coated aluminum frame. The coating which perfectly works in terms of wear resistance turned out to generate some prominent burrs at machined surface edges which were removed, but with the delay still remaining. It was found that the elastically bent spring lever slightly touches the aluminum structure. The situation was resolved by adding small pieces of Kapton® between the frame and the spring levers, after which the release worked reliably and instantly.

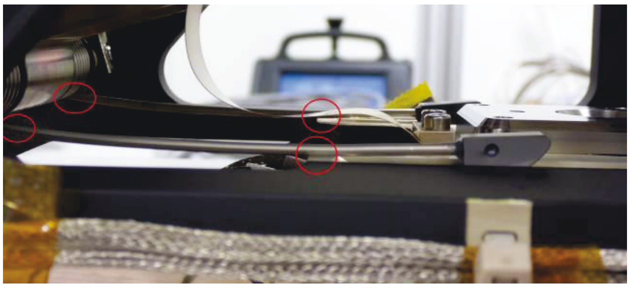

FIGURE 8. Aluminium frame with the spring levers and the contact points marked

The following table summarizes some of the achieved results from the qualification.

Requirement	Quantity
Accuracy of operational (actuated) position	+/- 8.3 arcmin
Mirror stability in operational (actuated) position	+/-0.19 arcmin
Operational temperature range	-10°C / 50°C
Non-operational temperature range	-30°C / 70°C

TAB 2. SSM qualification results

The shock emission tests have been successfully executed and no damage was detected. Two peaks could be extracted from the data in y- and z-direction. One peak is interpreted as Frangi actuation (bolt breaking), the second as hitting the elastic the end stop bar. The shock levels at SSM mirror reached values of about 1800 g. Currently the reduction of the shock is further investigated by reducing the bolt preload. In parallel the rated break force of the bolt has been decreased to still guarantee safety of the release of the fail safe function.

One objective of the QM testing was to evaluate the cleanliness procedures and measures for the FM. The SSM environmental testing campaign foresaw a hermetical sealing under foil. For that reason the application of acceleration sensors was done in cleanroom environment prior transport to the test facilities. However two weak points in the contamination control were identified. The health check requires a release of the fail safe mechanics and consequently a refurbishment in laboratory environment. Second the TV testing requires a venting of the foil cage. These events were tracked with specific witness samples. An unplanned issue which worsen contamination budget was the questionable outgassing behaviour of the covering foil under TV test conditions. The decision to remove the foil tent in the chamber turned out to be a great portion of the overall particular contamination gained during testing. Afterwards a material test of the used foil showed that outgassing would have been compatible to TV environment and removing the foil tend was unnecessary.

6. LESSONS LEARNED

Interface definition and reasonable sharing of responsibilities is a major concern to be regarded during requirement elaboration, but also during tender considerations. Besides others attention should be paid to:

– Separable mechanical contacts
– Interfaces to subcomponents with limited possibility of dismounting

Even if not required for QM the verification of cleanliness procedures during MAIT gives valuable inputs for later FM phase and reveals leaks like for instance:

– Material compatibility and usability
– Possible unforeseen events in contamination control planning
– Underestimated contamination contributors and their approximate quantification

The temperatures measured by the temperature sensor integrated in the Frangi actuator differ for nominal and redundant circuit. This is normal, as the nominal and redundant heater circuits are arranged differently inside of the actuator, and wrt the Frangibolt and the temperature sensor. For a transient event, such as heating up quickly as during release, the temperature reading therefore will not reflect the true temperature in the bolt or in the heater. It indicates the proper functioning of the heating circuit and an order of magnitude for the temperature.

7. ACKNOWLEDGMENT

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