"BACKLASH-FREE" GAS-TIGHT HIGH PRECISION SAMPLE HANDLING MECHANISMS – LESSONS LEARNED FROM QUALIFICATION TESTING & DESIGN AND LESSONS LEARNED OF THE CORE SAMPLE HANDLING MECHANISM (CSHS) ON THE EXOMARS 2020 ROVER

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ABSTRACT

This paper presents two topics from the Sample Preparation and Distribution System (SPDS). The first part presents the lessons learned from qualification testing on dynamic seals and the pre-loading concept of the drive train to achieve high positioning accuracy in an ultra-clean environment through a leak tight seal.

The second part describes the design and lessons learned of the Core Sample Handling System (CSHS) which is the first in a series of SPDS mechanisms and serves to receive Martian sample from the rover-mounted drill and to convey it into an ultra-clean environment for further processing.

The SPDS is developed and tested by OHB System AG as part of the rover of the European Space Agency's ExoMars Mission under subcontract to the mission prime Thales Alenia Space. The ExoMars mission, planned for launch in 2020 is a European Space Agency and ROSCOSMOS cooperation with contributions from NASA in the scientific payload and data communication.

1. INTRODUCTION

Exploring whether life ever existed, or is still present on Mars today, is one of the most exciting scientific questions of our time. Therefore ESA, together with Roscosmos, decided to conduct the ExoMars program, which is divided into two missions, an orbiter that was successfully launched in 2016, and a lander with a rover in 2020. The rover is equipped with a drill to take sub-soil samples from a depth down to 2 m, which will be analyzed in-situ by several instruments on the rover, the so-called Pasteur payload. These are located in the Analytical Laboratory Drawer (ALD) inside the rover, namely:

- MicrOmega, a visible and IR imaging spectrometer
- Raman Laser Spectrometer (RLS)
- Mars Organic Molecule Analyzer (MOMA) consisting of a Laser Desorption Mass Spectrometer (LD-MS) and a Gas Chromatography Mass Spectrometer (GC-MS), including a mechanism to seal the ovens (the so-called Tapping Station)

In order for these instruments to perform their analyses accurately, the rover is equipped with the Sample Preparation and Distribution System (SPDS) which is also part of the ALD and represents one of the key components of the 2020 mission [1]. It is developed by OHB System AG as subcontractor to the mission prime Thales Alenia Space. To ensure the required cleanliness for the highly sensitive instruments, the ALD and the SPDS form an enclosed volume, the so-called Ultra-Clean Zone (UCZ), which is pressurized until the first opening on Mars to avoid contamination.

The SPDS (see Fig. 1) consists of four separate mechanisms that interact with each other to transport the sample within the UCZ. The Core Sample Handling System (CSHS, [2]) receives the sample from the rover mounted drill and transfers it to the Crushing Station (CS, [5]), where it is crushed to a defined grain size range. The Powdered Sample Dosing and Distribution System (PSDDS, [4]) receives the powder and doses it in defined quantities to different sample receptacles, which are brought to the instruments for analysis by the Powdered Sample Handling System (PSHS, [3]).

The remainder of this paper is structured as follows:

- The design drivers for the SPDS are described in chapter 2.
- Chapters 3 and 4 describe the design and testing of

the dynamic seals used in the SPDS focussing on the lessons learned obtained during the qualification process.
- Chapters 5 and 6 provide the design description of the preloaded drive train and the results of the testing focussing on lessons learned.
- Chapters 7 and 8 present the CSHS design and the lessons learned during the integration and the qualification test campaign.
- Lastly, Chapter 9 contains a short summary providing the lessons learned and a short outlook regarding the SPDS

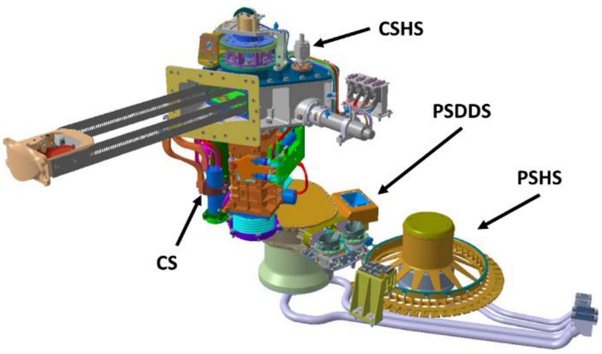

Figure 1. SPDS FM CAD model

2. DESIGN DRIVERS

The design drivers for the SPDS can be divided into four main groups:

- Design drivers originating from sample properties and sample handling
- Design drivers imposed by the instruments
- Design drivers derived from the cleanliness and contamination control requirements of the mission and the sensitive instruments
- Design drivers imposed by the planetary environment on Mars

The first group of design drivers all require a certain robustness of the mechanisms against existing sample and dust. As the samples received from the drill can vary from almost solid cores over broken pieces to regolith, the SPDS needs to be able to process a large variety of samples independent of their state and constitution.

The second group of design drivers are imposed by the instruments and their needs for sample preparation and presentation. Besides the required grain size range, a certain flatness of the presented sample and a defined sample quantity, one of the major requirements is the positioning performance for correct sample presentation. In the case that an optical instrument discovers an interesting grain within its field of view on the refillable container of the PSHS, the aim is to subject this one grain to a subsequent series of investigations by different instruments. To achieve this, the sample receptacle has to be positioned with an accuracy of ±100 µm on its diameter of 240 mm, which is equivalent to an angular accuracy of 0.05 degrees. To perform a complete analysis of particular interesting areas of the sample, the instruments need to scan it in steps of 20 µm, requiring a command resolution of 0.01 degrees (see [6]).

The third group of major design drivers is imposed by the cleanliness and contamination control demands raised by the mission itself, and the sensitivity of the instruments. It shall by all means be avoided that any kind of contamination originating from earth leads to false measurements by the instruments. As that could invalidate all potential findings on Mars a maximum contamination of 0.03 spores per square meter and maximum 50 ng contamination level per gram of Martian sample delivered to ALD Scientific Instruments are imposed on the hardware. For this reason, an UCZ was implemented in which the SPDS mechanisms shall operate.

To keep contamination out, this UCZ needs to be pressurized from the moment of its closure during integration in a highly clean environment (ISO3 AMC-9 (or) glove box, developed by and located in Thales Alenia Space, Torino premises) until first opening on Mars. Since actuators as well as sensors and other electrical components are a high source of contamination, SPDS actuators and electronics are not allowed inside the UCZ. This calls for dynamic feed-throughs that on the one hand need to be gas-tight and, on the other hand, need to avoid high parasitic torques to allow smooth motion and a low system weight. These are two challenging requirements that drive the need for an optimized compromise to be able to meet requested performance within the allocated resources. Furthermore all structural parts of the mechanism that enclose the UCZ need gas-tight seals on their interfaces requiring a stiff structure with a minimum number of internal interfaces.

Other origins of contamination are different types of materials or coatings. Basically the only material group accepted inside the UCZ is metals. When unavoidable a very limited use of specific polymers and low temperature grease is allowed. Also the choice of coating is limited by several factors such as the chemical compatibility to the instrument requirements, as well as the demanded robustness and surface roughness (Ra = 0.1 - 0.2 µm maximum for all surfaces in contact with sample) to be compliant to the ultra-cleaning procedure, which includes bake-outs, ultra-sonic baths with different solvents, CO_2 snow-cleaning and a sterilization process.

Last but not least, the environmental conditions on Mars impose several restrictions on the design, such as the operative temperature range of -60 °C to +40 °C, and the dry low-pressure CO_2 atmosphere. In contrary to the sterile vacuum in which most space mechanisms operate, the sample processing produces a very dusty environment, imposing many challenges for the mechanisms tribological elements. The dry atmosphere causes additional triboelectric charging of the particles which can cause them to stick to all surfaces they come in contact with. The UCZ is thus converted into an extremely dirty (but uncontaminated) environment during sample handling.

3. DESIGN OF THE DYNAMIC SEALS OF THE SPDS TO ACHIEVE GAS-TIGHTNESS

As mechanism interaction with sample shall take place encapsulated inside the UCZ with all major contamination sources such as actuators and sensors remaining outside of this zone, all drive trains require a leak-tight dynamic feed-through with very low resistive torque. The leak tightness needs to be maintained over the entire temperature range from -60°C to +70°C for a delta pressure of 100mbar Helium. This leak tightness shall be maintained even after mechanism actuation. To realize this, the SPDS is equipped with dynamic seals consisting of the low temperature Braycote 601EF grease that fulfills the sealing function, placed either inside a reservoir or a labyrinth, and using PTFE rings preloaded with springs to keep the grease in position. The SPDS hosts three different types of dynamic seals:

- Radial seals for small shafts (Ø 6 – 10mm)
- Radial seals for large shafts (Ø 60mm)
- Axial seals for large shafts (Ø 100mm)

The design of an example small radial seal can be seen in Fig. 2 Two U shaped PTFE seals, pre-loaded with pre-tensioning springs inside, are hosted in the static housing. They work as limitation for the grease reservoir, which is filled by a radial hole. During the filling the shaft is rotated to ensure proper filling of the reservoir until grease exits the radial exit hole of the reservoir. Prior to this filling, also the U shaped PTFE geometry is filled with grease, which needs to be done with high precautions to avoid air bubbles that may, in a vacuum, destroy the sealing function.

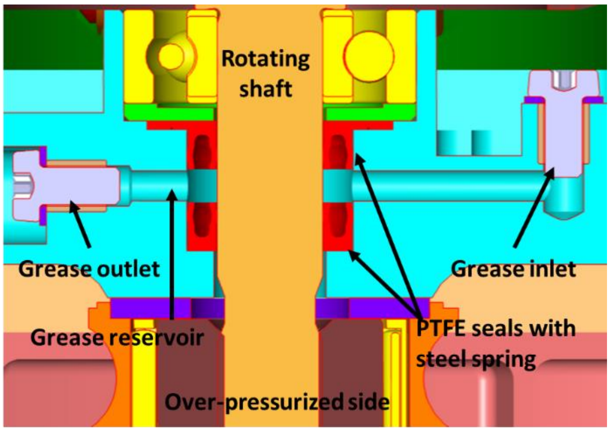

Figure 2. Design of "small" radial dynamic seal

A slightly different sealing solution is applied for the large shaft seal where the limited design envelope did not allow for a large grease reservoir. Here the two PTFE seals enclose a labyrinth filled with grease (see Fig. 3). As the rotational speed is very low (<0.5 rpm) this solution maintains its leak tightness under motion and all environmental conditions. The sealing rings have a very low stiffness to minimize the parasitic torque. This is acceptable because the sealing function is entirely realized by the grease.

The third seal type is an axial dynamic seal and realized by one single (axial) PTFE ring and a more complex labyrinth to keep the grease in position (see Fig. 4). These solutions work with differential pressures up to 0.22 bar (proof pressure) without degradation and for speeds lower than 0.5 rpm. The resistive torque of the order of 2 Nm is small compared to the size of the sealing.

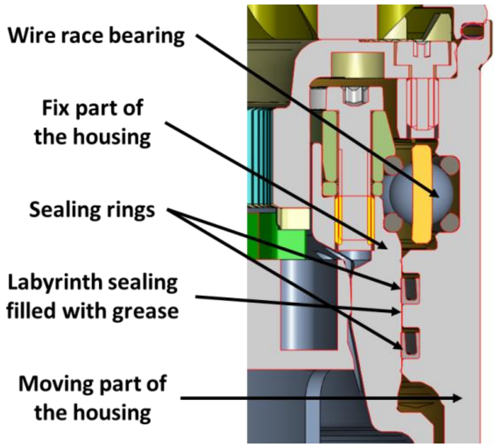

Figure 3. Design of "large" radial dynamic seal

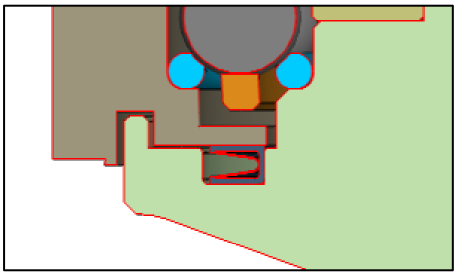

Figure 4. Design of axial dynamic seal

Other sealing methods such as O-rings or polymeric seals supported by springs had to be discarded due to the relatively high parasitic torques and the limitations imposed by the mission on the material selection for the UCZ. Breakable seals were ruled out since they do not allow motion of the mechanism for testing and lose entirely their sealing function after breakage, so contamination from the drive-train and the interior of the rover would be able to pass through it. In addition, the breaking could create particles that constitute additional contamination. Also magnetic feed-throughs had to be dismissed because they cannot provide sufficient accuracy and strength within the available envelope and mass budget to achieve the required accuracy. [3]

4. QUALIFICATION TESTS AND LESSONS LEARNED OF THE DYNAMIC SEALS

The extensive qualification test campaigns of each of the SPDS subsystems provided several lessons learned:

- Each seal type/arrangement requires a suitable

breadboard with flight seals, correct grease and flight like geometry (and tolerances) to test its suitability in an early stage and to investigate the ideal integration procedure as this is a key point regarding its functionality and reliability
- In case a bake-out is required, a suitable procedure can avoid any alterations of the seal rings or the grease by the bake-out process that would lead to an impact on the seal performance.
- Radial seals for small shafts require a grease reservoir which is radially filled. Axial filling can often lead to enclosed air bubbles that later destroy the leak tightness.
- However, air bubbles are critical to all seals and need to be avoided as far as possible
- Fill the PTFE seals with grease prior to integration and put them in vacuum to remove trapped air.
- Already avoid air bubbles inside the syringe by putting it under vacuum (grease volume can shrink up to 50%).
- Use as much grease as possible during the integration to guarantee a good filling of the sealing, but while doing so, ensure that the grease does not exit the system at undesired locations (e.g. enters adjacent bearings)
- Especially the larger radial seal rings require suitable chamfers to avoid damage during integration. In case this is not possible the orientation can be switched as long as the delta pressure (100 mbar for SPDS) is quite low.

During the qualification test campaign each mechanism sub-system was tested individually. As each mechanism contains several static and dynamic seals, only the overall leak rates can be measured. Anyhow, as long as design guidelines for static seals are met, the dynamic seals provide the largest contribution to the detected leak rate.

Exemplary plots for the leak rate under different qualification temperatures can be seen in Fig. 5. The most critical temperatures regarding the leak performance are high temperatures as the grease is less viscous and therefore more permeable for Helium. However, the most critical temperature from functionality point of view are low temperatures. Tests proved that any problems within the design or the integration of the seal will reveal themselves most likely at minimum temperature. On the other hand, if a seal works, also the leak rate is much lower than for high temperatures – even during and after motion.

5. DESIGN OF THE PRE-LOAD DEVICES OF THE SPDS TO ACHIEVE POSITIONING PERFORMANCE

Several project constraints lead to the necessity of a pre-torque device over several gear stages:

- To reduce possible contamination, the use of sensors is prohibited inside the UCZ (and therefore on the output shafts).
- The Instruments require a very high positioning accuracy to subsequently investigate selected sample grains.
- The target is to keep the electronics as robust and therefore simple as possible which prohibits the use of complex high-performance sensors

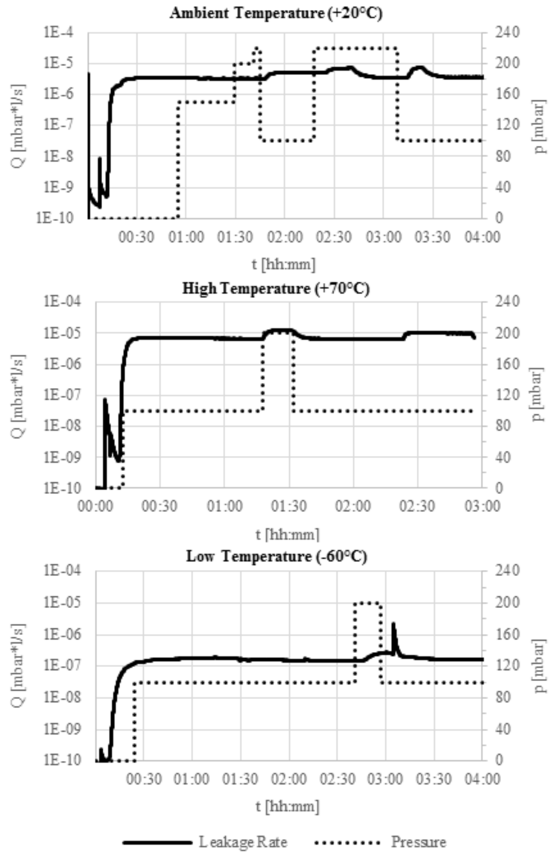

Figure 5. Leak plots for ambient, max. and min qualification temperature

Due to the reasons mentioned above, a design is required that can provide a position accuracy of 0.01deg with an encoder located on the motor shaft that has a resolution of 45deg. This is achieved by pre-torqueing three planetary gear stages encapsulated in a gear-box provided by Maxon and two spur gear stages, one driving the output shaft and the other one hosting the pre-torque device. The total gear ratio is 13876.5:1 reducing the encoder resolution to 0.004 deg on the drive-train output shaft.

The pre-torque device (see Fig. 6) consists of two gears located on the output shaft of the actuator, that are pre-torqued with a leg spring in opposing directions. One of them is fixed on the actuator output shaft and the other one can be subjected to relative motion. Each meshes with one of the gears on the input shafts of the two adjacent gear-boxes. The output shafts of the gear-boxes are also equipped with spur gears that mesh with the same internal ring gear to sum up the previously separated torques again. During integration the internal ring gear is fixed and both gears on the actuator output shaft are rotated in opposing directions until all backlash of the gear stages in between is removed. Subsequent to this a pre-torque is set by tensioning a leg spring between the spur gear that is connected to the actuator and the pre-torque cap whose position relative to the free spur gear is fixed with screws. When the desired pre-torque is set, the device can be locked with the central screw. This locking ensures that the pre-torque is set to a constant value and not dependent on the spring elasticity. [3]

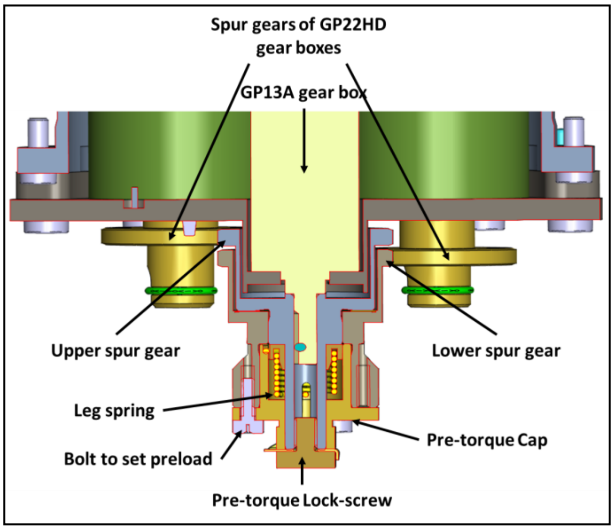

Figure 6. Pre-torque Device.

When the actuator induces a torque in the system it is divided onto the two parallel drive-trains. For one drive-train it is added to the pre-torque and for the other one it is reduced. The system is “backlash-free“ as long as the induced torque is smaller than the pre-torque. On the internal ring gear both torques are again summed-up to provide the necessary torque for mechanism actuation. [3]

6. LESSONS LEARNED REGARDING THE PRE-LOAD DEVICE

The positioning performance that can be achieved with the pretorque device is based on two factors: The calibration curve, that compensates manufacturing tolerances on the gears (especially on the last gear stage) and the bearing, and the zeroing which is made at a hard stop as the sensor is incremental. During the qualification campaign several lessons learned were made:

- After first integration the mechanism requires a run-in time also with several zeroings due to setting effects.
- The hard-stop needs to be protected from grease and particles (avoid wear especially on last gear stage)
- Preload the outer flanks of the last gear stage to have a stiffer system
- When the preload device needs to be opened due to integration activities, always completely remove the spring to ensure it is completely unloaded during re-application of the pre-load
- Correctly measure the pre-load during integration and do not rely on torque-path relations of the spring.
- Carefully select the preload values as optimum of the available torque/current of the actuator and the allowed backlash of the mechanism.
- Use a zeroing procedure that can provide the same results under all relevant temperatures.

7. DESIGN OF THE CSHS

The Core Sample Handling System (CSHS) is the first in the chain of the four SPDS sample handling mechanisms and forms the input interface for the drill samples to the ALD. It was developed by Hoch Technologie Systeme GmbH (HTS) and OHB System AG. It provides functionality for the sample handover of drill samples and of stored blank samples to the SPDS. Furthermore it needs to seal the UCZ against the environment during ground operations and flight as it is the only mechanism with a dedicated opening, the so-called ALD door.

To fulfill its tasks, the CSHS is composed of three sub-mechanisms (see Fig. 7). The Core Sample Transport Mechanism (CSTM) moves the delivered drill samples from the drill sample discharge point into the UCZ to the Crushing Station (CS). To cope with the limited envelope the sample container which transports the sample is attached to two metal belts. The belts are bent similar to tape measures to increase their stiffness. Translational movement of the carrier is achieved by furling and unfurling the belts. Each belt is attached to a torsion spring which supports the furling. To extend the belts an actuator is required. This actuator drives four worm gears, two of them rotate the shafts around which the belts are coiled and the other two drive toothed wheels which directly move the belts by meshing with a perforation.

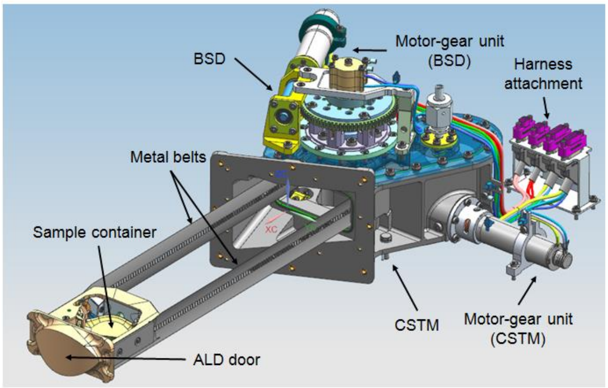

Figure 7. CSHS FM CAD model

The Sample Container (SC) is the second sub-mechanism as it is equipped with a passively actuated trap-door to discharge the sample into the CS. While the Sample Container is extended, two dredger-like shovels are closed and can store a solid or granular sample. As soon as the Container is moved into position above the CS a pin triggers the spring-loaded mechanism and the shovels are opened and release the sample. This mechanism is described in detail in [2]. A second important functionality of the Sample Container is that it is also used to seal the only dedicated opening of the UCZ. To do this, a static seal is implemented between the housing and the container's front. As the compression force for the seal cannot be applied through the belts a release bolt is introduced which also works as launch lock for the sample container.

The third sub-mechanism is the Blank Sample Dispenser (BSD). It is designed to provide a total of 6 ultraclean samples, the so-called blank samples. These are spherical ceramic samples with a known chemical composition used for instrument calibration on Mars. Each of these samples is stored individually in its own blister package in order to have them protected against contamination (see Fig. 8). The BSD is mounted on top of the CSHS directly above the interface between the CSHS and the CS. In doing so, the released blank sample drops directly through the opened shovels of the Sample Container into the CS. The blister packages are placed directly on the CSHS lid and each one is sealed against the UCZ. Releasing the blank samples is then realized by squeezing the blister packages with stamps in order to rupture the foil on the UCZ side, while keeping the remaining part of the blister intact to make sure that the UCZ stays sealed. For each of the blister packages there is an individual stamp placed and guided above it. The stamps are actuated by a wheel with a ramp which is rotated by an actuator. The ramp is designed in a way that it is possible to entirely compress one blister without moving any other stamp.

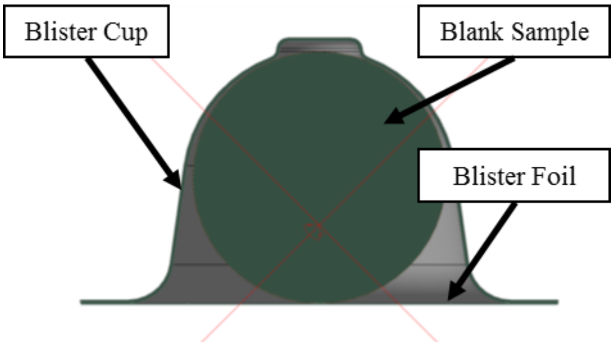

Figure 8. Section through Blister Package

8. LESSONS LEARNED OF THE CSHS QUALIFICATION TEST CAMPAIGN

During the integration and testing of the QM several lessons-learned were obtained. As indicated above the CSTM drivetrain consists of four worm gears driven by a single shaft. This shaft is supported by two ball bearings and is lead through a dynamic seal to connect it to the actuator (see Fig. 9). During the integration it was found that the drive shaft was blocked completely when all four worm wheels were installed. Investigation showed that the worm wheels were not manufactured correctly and that the distance between the axles did not leave sufficient clearance to compensate the over constraining by the four output shafts. As the correction of the positions of the axes requires a complete new housing this was also compensated by additional rework of the gears. After that rework the integration worked properly with the no-load torque being in the expected range.

In the FM design of the CSHS the following changes were applied:

- The tolerances of all components of the drive train (distances between axles, worm shafts and –wheels, support bracket) were reassessed to ensure proper functionality of the drive-train although it is overdetermined
- The corresponding worm shafts and wheels are not only ordered from the same manufacturer and initially sampled but are also delivered on a jig representing the correct positions and providing the possibility to test the correct meshing and functionality of the components prior to the integration (see Fig. 10).
- The possibility to adjust the axial position of the worm wheels with respect to the common worm shaft.

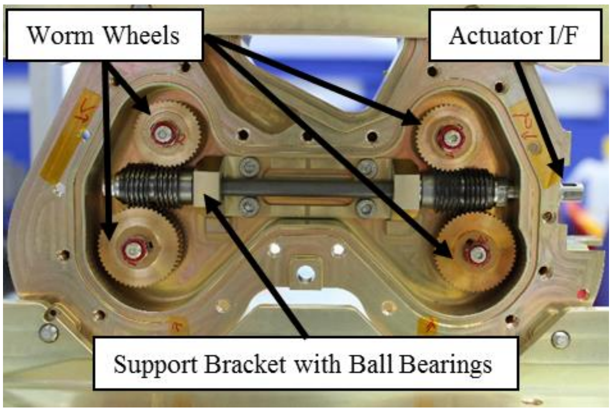

Figure 9. CSTM Drive Train

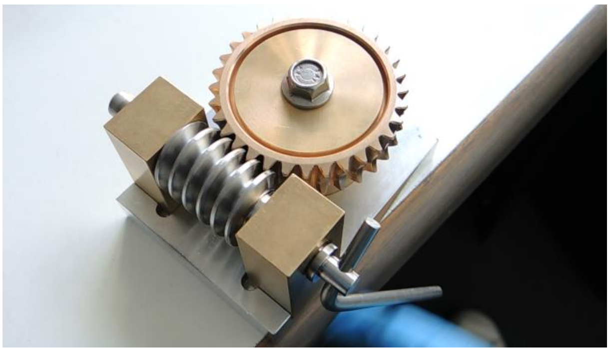
Figure 10. Example for jig to test gears

Another challenging item in the CSHS is the release bolt as extreme care needs to be taken during installation in order to ensure a reliable release. In the CSHS the release bolt is attached to the SC inside the UCZ while the actuator is mounted outside the housing. As the bolt is ruptured by stretching it, all parts in the load path need to be extremely stiff to not compensate the elongation of the actuator. Furthermore, in the specific design of the CSHS, it needs to be made sure that there are no gaps between components in the load path. During the first functional tests with the QM it was discovered, that this was the case when the actuator fully expanded without breaking the bolt. After inspecting the parts the root cause was identified as a gap between the Sample Container and the support structure. This was caused by the over determined mounting of the SC as it needs to compress the ALD Door Seal at its front and should have contact to the structure at its backside, in the so-called Cup/Cone interface, as well (see Fig. 11). As a stiff metallic O-ring shaped seal was initially planned for the ALD Door Seal the contact in the Cup/Cone interface was hard to achieve as there is no direct way of measuring the gap. Due to the stiffness of the seal and the high forces at the bolt also elastic deformations of the Housing, the SC and the other components like shim and cone need to be taken into account. And these deformation also depend on the torque with which the bolt is fastened. The investigation showed that the torque with which the bolt was fastened was too low as the parasitic torques were higher than expected which resulted in a decreased pretension. This was for example caused by missing coatings as the parts need to be compatible to the cleaning processes.

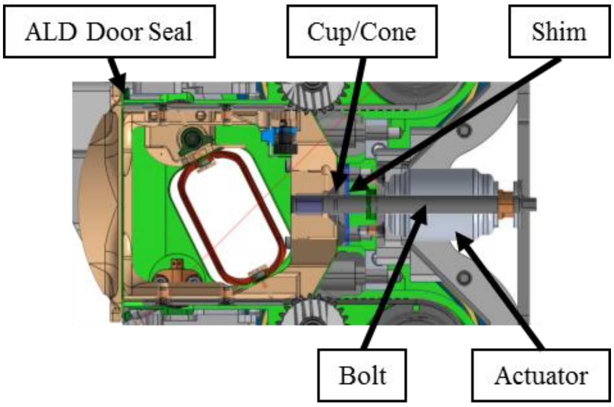

Figure 11. Section through the Release Bolt

As a result, the relation between torque and pretension was assessed in an additional test setup which included a load cell. The results showed that the torque needed to be increased significantly which increased the risk of breaking the bolt during integration. To cope with that risk a MGSE was developed to block the bolt's rotation and thus absorbing the torque.

From this failed attempt the following conclusions could be drawn:

- The load path of a release bolt needs to be as stiff as possible and only materials with a high compressive strength should be used.
- In complex designs it should be made sure that there will be no gaps, i.e. a way to measure or confirm the correct position is needed.
- A load cell to measure the pretension should be installed.
- If no load cell can be installed, the parasitic torques (nuts, seals, etc.) need to be assessed accurately.

Another issue with the release bolt is the shock that is induced in the system when the bolt breaks. When the shock at the CSHS was measured during the QM test campaign it was found that the levels exceeded the limits significantly especially at high frequencies. In an attempt to reduce the shock loads the release bolt was replaced by a significantly weaker one (i.e. with a reduced breaking load) which also required to change the ALD Door seal. With the weaker bolt, the required compression of the metallic seal could not be achieved so a soft silicone seal was introduced. The shock loads however could be reduced.

The lesson learned from that is that tests of shock emitting components should always be carried out as early as possible in the design process as a reliable prediction is very difficult. Even if the design might not yet be fully flight like at the early testing at least the criticality of the shock can be evaluated and possible shock reduction measures can be foreseen already at an early development stage.

For extraterrestrial in-situ sample analysis the possibility to calibrate the instruments is important in order make sure that the setup is not contaminated or to prove that possible findings are genuine. The blank samples for ExoMars fulfill this task. The blister packages in which they are stored consist of two parts which are soldered together: the cup which holds the sample and the foil which breaks at an engraved pattern when the sample is pushed out. To be able to process the samples correctly the blister cups must not break to keep the UCZ intact. The manufacturing of the blister packages is challenging as the cups are made out of thin deep-drawn metal sheets. The samples are then added and the foil and cup are soldered together at high temperatures and under vacuum conditions. This process is not as accurate as it is desired, as cup and foil expand at high temperatures and therefore cannot be centered properly. For a reliable operation, the relative position of the blank sample and the breaking pattern is crucial. Furthermore the centering of the cups with respect to the stamps which push-out the sample is equally important.

During the CSHS QM test campaign the two consequential problems were faced, namely that the sample was either not delivered properly or got stuck in the blister package, or that the blister cup ruptured during the process. The analysis of these problems lead to the following results:

- The accuracy during the manufacturing process is important. If the process cannot be adapted sufficiently a selection has to be made out of a larger manufacturing batch.
- It is important not to pre-stress the packages during installation. In the QM Design a clearance fit between the blisters and the structure was not ensured. Some blister had to be slightly pressed into their conical seats, leading either to a rupture (see Fig. 12) of the cup or resulted in a stuck sample. A clearance fit (at all operational temperatures) is strongly recommended for reliable sample release operations.
- The geometry of the rupture pattern in the foil is important and needs to be adjusted with respect to the sample geometry. Also the correct position of the blister package with respect to the mechanism is crucial. Extensive tests in early phases are advisable.

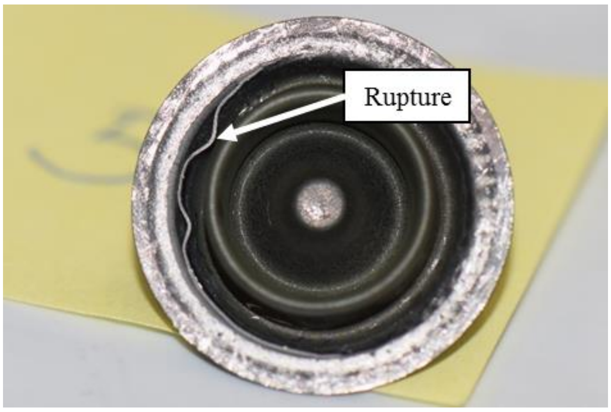

Figure 12. Ruptured Blister Cup

9. CONCLUSION AND OUTLOOK

The different design solutions for the dynamic seals proved to provide satisfying results on leak rate at a very low resistive torque under all environmental conditions. Key point for the correct functionality are the correct design and the integration procedure which required training on suitable test setups.

The pre-torque device enables the mechanism to achieve an accuracy of 0.05 deg through a leak tight dynamic seal with a robust and simple sensor on the motor shaft. Key points are the correct pre-torqueing method and a suitable software and EGSE to correctly perform the zeroing which is the basis for a suitable positioning accuracy.

For the Core Sample Handling System important lessons have been learned not only for the current mission but also for future mechanism and sample handling projects. Summing up, extensive testing of the positioning of complex manufacturing items (e.g. blister packages) and early breadboard testing of shock emitting parts with corresponding shock measurement is highly recommendable. Furthermore, complex drive train arrangements with gears should be tested on a breadboard with carefully chosen tolerances and corresponding shimming options. All this helps to identify risks and difficulties in an early project phase and to be able to avoid failures during QM testing.

At the writing of this paper the PSHS and PSDDS flight models are in the middle of the acceptance testing and FM integration has begun on the CSHS and CS. It is foreseen to complete these activities in the second half of 2017. In parallel the system level activities performed by the mission prime Thales Alenia Space are ongoing using the SPDS QMs. The delivered SPSD QM mechanisms are, ahead of the ALD level QM Test Campaign, completely disassembled and after replacement of parts worn out or contaminated by sample material, the extensive ultra-cleaning and sterilization process is performed.

Subsequently the integration of the SPDS mechanisms into the ALD-QM model takes place inside an ISO3 AMC-9 (or) glove box located in an ISO 7 HC clean room in which SPDS parts outside the UCZ volume are also integrated. After finalization of the integration process, the ALD system qualification campaign is carried out, in which, besides the standard test program (leakage, vibration/shock and thermal-vacuum), several blank samples and drilled samples are processed by the entire SPDS with subsequent analysis by the instruments to investigate the cleanliness and performance of the entire ALD system.

10. REFERENCES

1. Richter, L., et. al. (2015). Progress Report on Development of the ExoMars Sample Processing and Distribution System (SPDS) and Related OHB Sample Handling Studies. *ASTRA 2015*, ESTEC, Noordwijk, Nederlands, 11-13 May 2015

2. Melzer, Ch. et. al. (2015). Mechanical Testing on the Core Sample Transportation Mechanism of the ExoMars 2018 Mission, *ESMATS 2015*, Bilbao, Spain

3. Paul, Robert, et. al. (2015). "Development and Testing of a „Backlash-Free“ Gas-Tight High Precision Sample Handling Mechanism for Combined Science on the ExoMars 2018 Rover, *ESMATS 2015*, Bilbao, Spain

4. Redlich, D., et. al. (2016). Development and Testing of a “Backlash-Free” Gas-Tight High-Precision Sample Dosing Mechanism for the ExoMars 2018 Rover, *AMS 2016*, Santa Clara, USA

5. Paul, Robert, et. Al. (2017). Sample Flow and Implications on Design and Testing for the SPDS Mechanism Chain on the ExoMars 2020 Rover, *ASTRA 2017*, Leiden, The Netherlands

6. Lopez-Reyes, G. (2015). Development of Algorithms and Methodological Analyses for the Definition of the Operation Mode of the Raman Laser Spectrometer Instrument, Universidad de Valladolid, Valladolid, Spain