SAMPLE FLOW AND IMPLICATIONS ON DESIGN AND TESTING FOR THE SPDS MECHANISM CHAIN ON THE EXOMARS 2020 ROVER

R. Paul[(1)], D. Redlich[(1)], T. Tattusch[(1)], L. Richter[(1)], M. Thiel[(1)], F. Musso[(2)], S. Durrant[(3)]

[(1)]OHB System AG, Manfred-Fuchs-Str. 1, D-82234 Weßling, Germany
Phone: +49 81 534002 540, email: robert.paul@ohb.de
[(2)]Thales Alenia Space, Strada Antica di Collegno 253, I-10146 Torino, Italy
[(3)]ESA-ESTEC, Keplerlaan 1, 2200 AG Noordwijk, Netherlands

ABSTRACT

This paper presents the flow of the acquired Martian subsoil sample through the Sample Preparation and Distribution System (SPDS) and the implications that the different sample handling steps impose on the design and testing of each mechanism.

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 Rover and Surface Platform planned for launch in 2020 is a large international cooperation between the European Space Agency and Roscosmos with a scientific contribution from NASA.

The task of the SPDS is to convey drilled samples into an ultra-clean environment where these are milled, dosed and prepared in a way that allows subsequent investigation of selected grains by different optical instruments thus providing combined science. All steps of this process chain require interaction of the different mechanisms while avoiding sample contamination and minimizing cross contamination between subsequent samples. Furthermore the mechanisms face the challenge to be exposed to and to operate in a very dusty environment.

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 analysed 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), 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]).

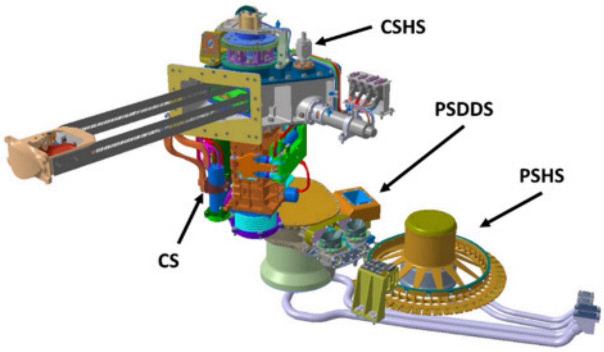

Figure 1. SPDS FM CAD model.

The remainder of this paper is structured as follows:

- The design drivers are described in chapter 2.
- Chapter 3 deals with the different possible sample types, their characteristics and their impact on mechanism testing
- Chapters 4 – 7 provide design descriptions of key components of the SPDS for sample handling along with major test results of the qualification testing: CSHS sample carrier, CS crushing jaws and dust protection lid, PSDDS Dosing station and Piezo vibrator, PSHS flattening blade
- Lastly Chapter 8 contains a short summary providing the lessons learned and a short outlook

2. DESIGN DRIVERS

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

- Design drivers originating from sample properties and sample handling
- 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. Also the sample types can range from soft, rather sticky materials such as clays to very hard stones. After the milling, all samples are in powdered form with grain sizes up to maximum 500 µm. This powder is subjected to triboelectric charging as the rover is not grounded in the traditional sense but only by interaction with the atmosphere [6]. This can lead to layer formation or clogging which shall be minimized to avoid loss of functionality. Possible fractions of water inside the sample together with hygroscopic samples can lead to cementation effects which shall be avoided. As this might not always be possible and scientists want to keep the possibility to store milled samples for a certain duration, the system requires to provide measures to loosen up cemented material.

The second 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 electronics are not allowed inside the UCZ. This calls for the need of 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 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 and 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. SAMPLE TYPES, CHARACTERISTICS AND IMPACT ON MECHANISM TESTING

As the exact constitution of the Martian subsoil is currently unknown, the SPDS needs to be designed to face a large variety of different materials with highly varying properties and behaviors.

Due to the huge amount of potential sample simulants to be tested, ESA led a scientific working group to establish the minimum subset of reference materials or simulants (already covering a broad range of sample properties) with which the SPDS shall be tested and qualified. . These reference simulants range from harder stones such as sandstone to softer materials such as claystone and gypsum (see Fig. 2). Furthermore regolith samples containing salts, clays and hygroscopic sands are taken into consideration and there is a distinction between ambient (wet by Mars standards) and dry (baked-out) simulants/materials. A special kind of regolith sample material are samples with a certain icy content. Here a major challenge is the fabrication of such samples for the testing and the correct insertion into the test chambers without losing the ice content during atmospheric evacuation and cool down. These reference samples are completed by a so-called *blank sample* which is made of fused silica. It is used in flight to calibrate the sample path and the payload instruments for any potential residual contamination to prevent false-positive measurement results.

In early project phases, e.g. phase A & B, SPDS design was focused on processing a certain type of samples, which were assumed to be the most critical ones. As an example the CS was originally tested with very hard materials assuming that the initial breaking force is the limiting factor for the crushing performance. After first SPDS BB were sized to process hard samples, SPDS performance in processing soft samples has been investigated. It turned out that this type of samples, e.g. gypsum and geyserite, can be very critical as well due to their tendency to stick to the crushing jaws causing jams and high actuation forces. Several small design improvements were able to solve these problems, clearly demonstrating the importance of an early definition/specification of the reference samples and/or simulants with corresponding proper and deep early testing. As a result, ESA defined the minimum set of reference samples and range of their key parameters to be considered for the SPDS verification.

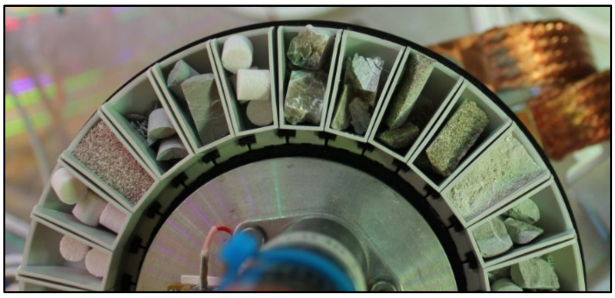

Figure 2. Test samples

Sample properties that are interesting for the SPDS suite of mechanisms are the following:

- Hardness (bulk and particle) --> Crushing performance and impact on tribological contacts
- Tendency to stick to surfaces --> cross contamination and clogging of mechanisms
- Tendency to be very loose in crushed status --> dosing/flattening performance (sample loss)
- Tendency to be very sticky (and form agglomerates) in crushed status --> dosing/flattening performance
- Uncrushed state (core / broken core / granular) --> Sample transport to UCZ, crushing and dejamming performance
- Water content and hygroscopicity --> cementing, storage

Key points for tests with samples are the sample preparation and the test environment. The sample preparation shall ensure that the sample does not experience temperatures or environments that alter the sample state, e.g. gypsum and salts are very hygroscopic and shall therefore not be exposed to high humidity. It is recommended to store the samples in a desiccator, which provides a defined, rather dry, environment.

Also it has to be considered that contrarily to the drive train, the worst case temperatures for sample handling are high temperatures as possible ice content can melt and lead to cementing. Even during ambient tests the present humidity in the test facility can lead to over-testing and problems may arise that would never occur under realistic conditions. For the correct test environment also the environmental pressure is important as triboelectric effects are much stronger in vacuum and lead to material adhering to surfaces.

Another point is the sample delivery to the tested mechanism. As a flight like delivery is in many cases not possible for mechanism stand-alone testing as it might be too complex, sample delivery has to be evaluated in detail so that it does not provoke undesired side effects, e.g. jams due to excessive sample spill (see Fig. 3).

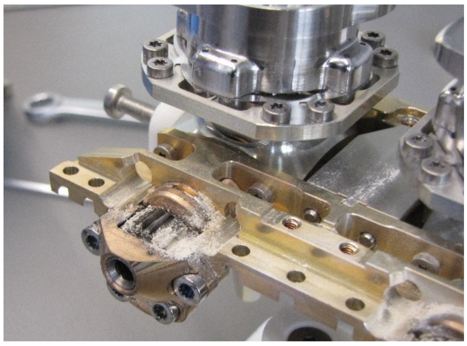

Figure 3. Excessive sample spill due to non-flight like delivery

4. CSHS SAMPLE CARRIER

The CSHS is equipped with a passively actuated Sample Carrier (SC) to receive the sample from the Drill, transport it into the UCZ and drop it in the CS. As suitable envelope/volume was not available to fit an appropriate actuator, the actuation had to be performed automatically when retracting the SC. The motion is performed via perforated metal belts that are driven by spur gears. For the sample dropping several concepts had been investigated and tested but had to be discarded for different reasons. A sliding door for example led to jams during breadboard testing as grains having entered the door sliding contact leading to wear, increased friction and potential door blockage. Other discarded concepts were:

- Single hinged flap door --> sliding contact
- Bevel geared door --> high actuation torque
- Mine cart --> long actuation path that is not compatible to the available envelope
- Retractable door --> required dynamic envelope too large.

The final solution, developed by HTS, which was implemented into the QM/FM, is a dredger concept (see [2]). A key point of this concept is the geometry and material selection for the dredger shovels. Both shovels need to be able to contain samples, independently of sample state and composition, which are injected inside the dynamic sample delivery envelope defined by the Drill. At the retraction point it has to be ensured that the entire sample is delivered without sample loss to the next mechanism and that spherical blank samples, that are stored in dedicated blister packages above the shovels, can pass these without disturbance. The required rotational degree of freedom is provided by sliding contacts on both ends, as no envelope is available to implement rolling contacts. Furthermore contacts are needed to transfer the required opening force. This leads to the complex geometry seen in Fig. 4.

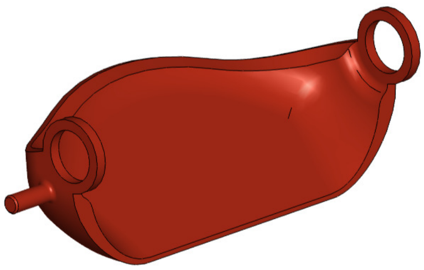

Figure 4. SC shovel

Besides this, the following requirements influence the material selection:

- Reflectivity < 0.3 (the high resolution camera shall take images of the sample inside the shovels to judge its suitability for scientific research)
- Surface roughness of $Ra \leq 0.2$ µm to provide the necessary cleanability of the parts as they are in direct contact with sample material
- High hardness (ideally >500 HV) at least of the hinges to minimize friction and wear in the sliding contact.
- Ideally no coating or a coating which is inorganic (in case of delamination, as the coating is a possible contamination source)
- Avoid Titanium (Titanium alloys have a poor triboelectric performance when in contact with sample, and powder tends to stick to it, [6])
- No organic materials
- No use of (fluid) lubricants
- Compatibility to presence of dust, especially when exposed to Martian environment during sample transfer with the Drill
- Compatibility to the Martian environment (-60 °C till +70 °C, 7 mbar CO_2 atmosphere)
- Manufacturability of the chosen geometry

The material that was selected is plasma nitrated PH15-5 which provides the best compromise suiting all requirements. The hinges are dry sliding contacts running on a bronze bearing which provides a good tribological counterpart to the steel with relatively low friction and wear. This contact is covered by a dust protection lid to prevent grains entering. Friction and cold welding tests for this specific solution were carried out by AAC (Aerospace and Advanced Composites) and show acceptable cold welding behaviour (see Fig. 5).

To determine weak points in the design, the SC breadboard was tested with excessive sample spill (see Fig. 6). However it is fundamental that the sample is delivered within a defined sample delivery envelope. As the sample can come in all variations a random delivery can always lead to blocking of the system.

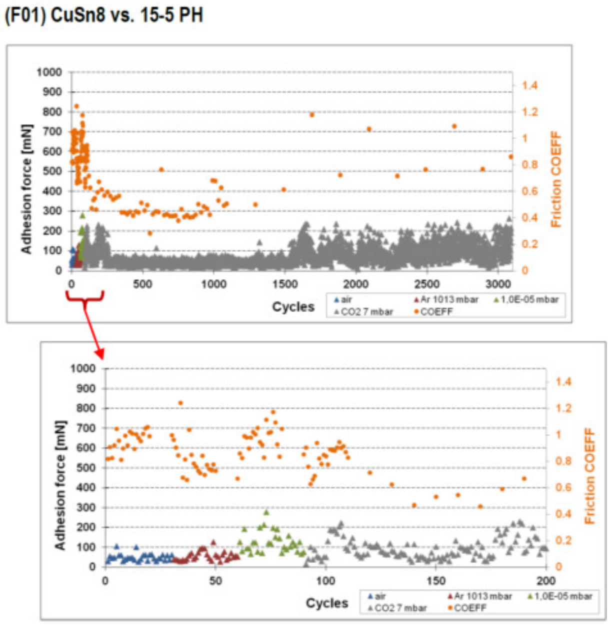

Figure 5. Friction coefficient and adhesion force of CuSn8 vs 15-5 PH (pin-on-disc test) performed by AAC

Figure 6. Sample testing with SC breadboard by HTS [2]

5. CS CRUSHING JAWS AND DUST PROTECTION LIDS

After the sample has been dropped from the CSHS SC it lands between the jaws of the CS. At this stage a checkpoint is done with the scientists to decide, based on the drill telemetry and the observations by the High Resolution Camera of the sample inside the SC, whether the sample shall be crushed or ejected from the system.

Key features for the CS sample handling are the crushing kinematics, the jaws and the dust protection of the drive train (see Fig. 7). The concept of the CS is based on a jaw crusher with one actuated jaw which follows a defined kinematic motion and a passive jaw that provides a certain elasticity.

The crushing mechanism has an eccentricity that causes the crushing gap to vary from 0.25 mm (smallest gap) to 0.5 mm (largest gap) during a complete turn of the crushing shaft. This gap size range was found to be the best compromise between needs to achieve a defined grain size distribution (the smaller the gap the finer the produced powder) and crushing performance (the larger the gap, the more robust and fast the crushing). Furthermore the kinematics provide the possibility to open the jaws to completely eject unwanted samples.

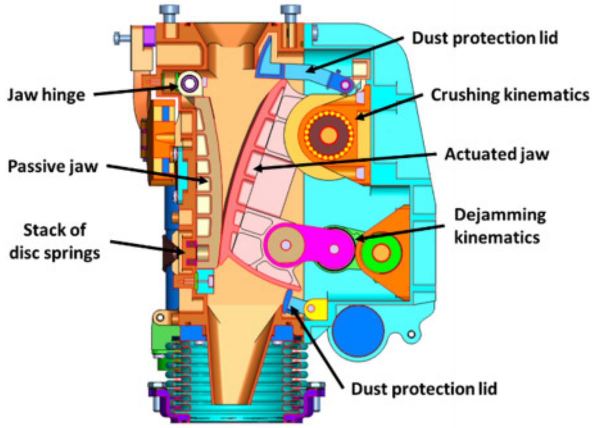

Figure 7. CS section showing the crushing kinematics

Another factor that impacts the sample crushing performance is the elasticity implemented into the passive jaw. Stacks of disk springs provide the counterforce for the crushing so the jaw performs small oscillations around its top hinge. This elasticity improves the crushing behavior as the implemented flexibility allows more powder to pass the jaws. Moreover it avoids jams and reduces the reaction forces on the drive train elements. As an additional feature, a hammer can hit on the backside of the jaw to loosen grains that stick to it. The induced shock affects the jaw only locally, as it is damped towards the remaining mechanism with metal damping pads.

Crushing can be performed in two directions: upwards and downwards. The downward crushing compresses the sample further during the crushing motion. Therefore the torque demand is much higher than for the upward motion where the crushed material expands. Optimum results were obtained by alternating the crushing direction after five rotations. The crushing process is velocity-controlled and therefore can be monitored by the current peaks that occur each time the sample is compressed.

Different jaw geometries were tested to improve the crushing performance. The jaw shape shown in Fig. 8 proved to be the best and is thus implemented in the final CS design. It has two striations that, in the beginning of the crushing, help to crack the cores and, in the end, to reduce the cross contamination due to powder sticking to the surface. The passive jaw has the negative profile of the actuated jaw. Both jaws are made of hardened steel. Coatings cannot be applied due to the mechanical interaction with the sharp sample grains.

The bearings, as well as the crushing and de-jamming kinematics, are protected from dust by small gaps between the jaw and the housing and the dust protection lids on the lower and upper end of the jaw. For better performance, both jaws have on each side sharp edges to minimize the contact surface to the sidewalls, reducing possible friction when dust enters these gaps. These edges work like blades that transport the grains away. Behind these blades the jaws provide a void that serves as a dust channel to direct the powder downwards.

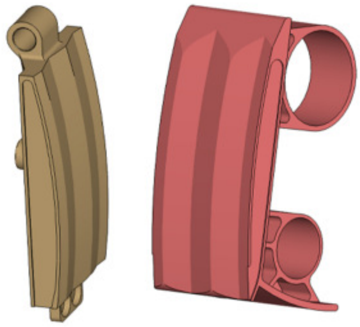

Figure 8. Shape of CS jaws (left: passive jaw, right: actuated jaw)

The dust protection lids are pre-stressed by torsion springs to follow the jaw motion without losing contact (even during launch to avoid rattling). Other concepts like bellows cannot be realized due to the small envelope and the large motions performed by the jaw (especially when opening for de-jamming).

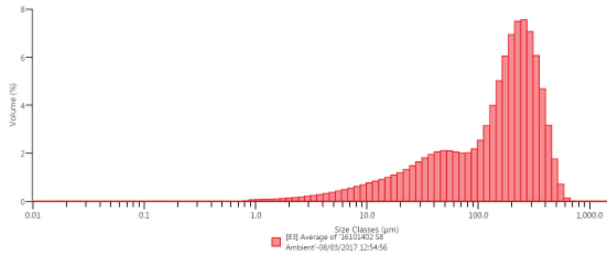

Figure 9. CS grain size distribution

QM testing showed that all tested materials are milled to the same grain size range (see example Fig. 9). Also the remaining cross contamination within the CS is minimized (see Fig. 10).

Figure 10. CS cross contamination

6. PSDDS DOSING UNIT AND PIEZO VIBRATOR

During the crushing process the sample falls right into one of the two redundant Dosing Units (DU) located on the PSDDS. Each consists of an inlet funnel to receive sample, a rotating shaft and an outlet funnel to guide the sample into the receptacles located on the next mechanism (see Fig. 11).

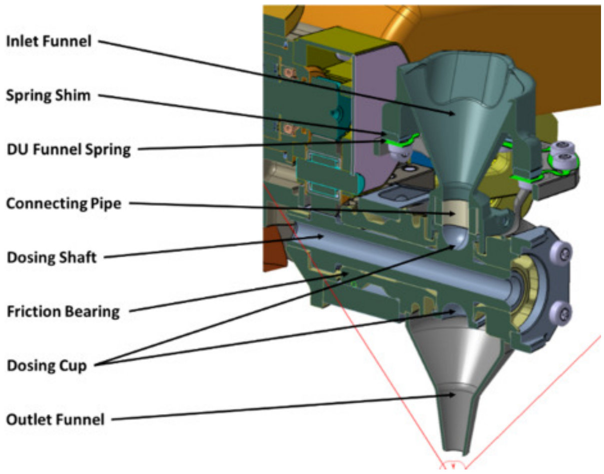

Figure 11. DU cross section

The dosing shaft provides two dosing cups spaced by 180° of 0.1 ml volume each. As this dosing concept requires a sliding contact with possible grains inside, in which wear shall be minimized (and cold welding avoided), the counterpart to the stainless steel shaft is a bushing made of Aluminum-oxide. This material is hard enough to avoid wear from sharp grains and is, due to its simple geometry, robust enough to survive launch loads which are generally very critical for ceramic parts. The inlet funnel provides the normal force for this contact by being pre-loaded by a stack of two leaf springs. The rotational degree of freedom of the shaft is provided by friction bearings made of bronze that are lubricated with Braycote 601EF.

Various breadboard tests showed that depending on the powder and the storage duration of sample inside the inlet funnel, a dosing is only reliable when the DU is vibrated. This vibration is realized by a Piezo vibrator which is located inside the hub and therefore outside the UCZ in which the DU operates. The vibration is transferred via an aluminum membrane to the DU (see Fig. 12). The DU are coupled at the lower part to the hub via a rigid joint in form of a 0.1 mm thick steel sheet that allows a slight rotation caused by the vibration. The center of rotation lies in the pitch point of the two spur gears of the dosing shafts. The Piezo itself is driven with a square profile of frequencies between 0 and 500 Hz. QM tests showed that a vibration at 150 Hz is best to loosen up sample and to ensure reliable dosing without disturbing sample that may already be on the receptacles of the PSHS.

Additionally, to reduce cross contamination under Mars-like conditions the material of the inlet funnel and the dosing shaft are both made of stainless steel, which is polished on its sample contact surfaces. Experimental data showed that this material choice is beneficial in comparison to aluminum or titanium surfaces as the triboelectric charging, and therefore the adherence to surfaces, is lower than that of the latter [6].

The geometries of the funnels and the mechanism concept were successfully tested with the breadboard on parabolic flights under Mars-like (0.4 g) and even Moon-like (0.1 g) gravity. As the outlet diameter is limited to 4 mm to ensure correct sample transfer to the MOMA ovens, the outlet funnel has been shaped in a way to ensure a straight fall-out of the sample even when the rover is not perfectly level.

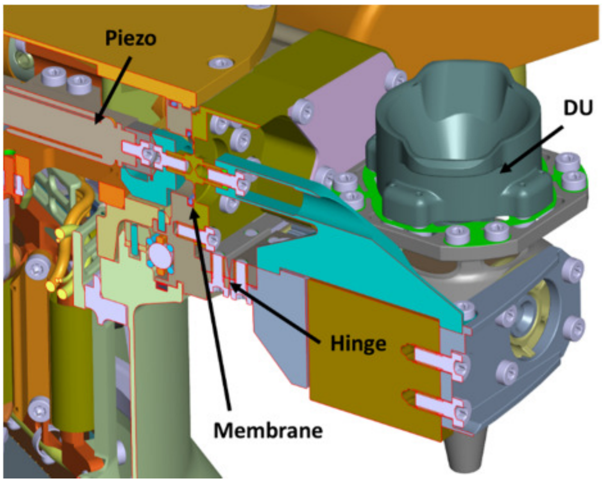

Figure 12. Piezo cross section

Qualification testing provided a dosing accuracy of +/- 15µl with 100% success rate. Also the cross contamination is very low (see Fig. 13).

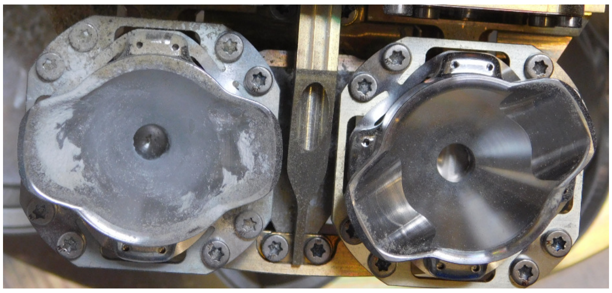

Figure 13. DU cross contamination (Mars-like conditions)

7. PSHS FLATTENING DEVICE

The PSDDS DU doses the powdered sample material in defined quantities into the sample receptacles that are located on the circumference of a carousel-like mechanism, the PSHS. The receptacles are 32 one-time use ovens that are contributed by the MOMA instrument, and a refillable container (RC) to allow measurements with three different optical instruments.

To meet the target of avoiding complex focusing mechanisms on all three instruments, a flattening device has been implemented in the PSHS (see Fig. 14). By performing its rotation, the PSHS drives the RC underneath a blade that flattens the sample to a flatness of +/- 100 µm with respect to a defined sample investigation plane. The vertical DOF of the blade is provided by a solid state hinge that is realized by a thin metal sheet to avoid sliding interfaces. The blade is passively pushed down by springs and lifted by the carousel rotation via a sliding shoe that runs on a rail of the PSHS carousel to avoid hitting the ovens.

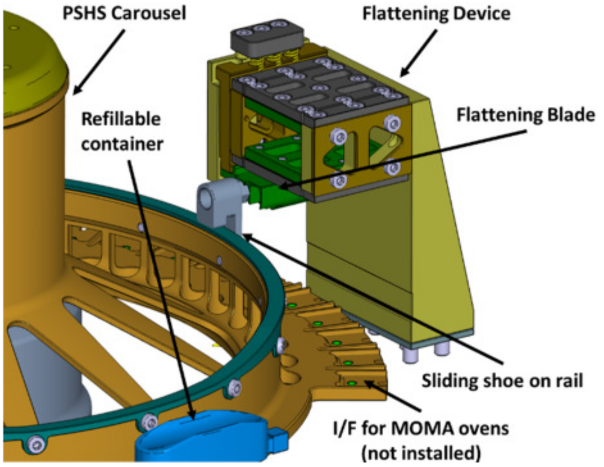

Figure 14. PSHS with Flattening Device

Tests have shown that the best flattening results are achieved when the powder is compressed before the actual flattening takes place in form of a scraping motion. Therefore the flattening blade is designed with slopes that push the powder down (see Fig. 15). In the middle part of the blade is the scraper next to which are free spaces where the powder that is scraped away can go. The material of the flattening blade is steel which shows only very low cross contamination as only few material adheres to it.

Other concepts to flatten samples were tested in early project phases but were discarded for different reasons:

- A piston (pressing from top) suffered from sample sticking to it (this effect may be even more severe under Martian conditions due to the triboelectric effect).
- Flattening with a roller had similar results as the piston
- Vibration does not provide reproducible results and does not guarantee that the surface is at a certain level. It would also require an additional actuator introducing additional complexity to the system.
- Flattening with a flexible blade provided good results but caused unwanted material spill towards the adjacent ovens due to the flicking of the blades when they loose contact to the RC. The possibility of using screens to protect the ovens was discussed but discarded due to envelope and mass problems

However intense testing showed that not only the shape of the flattening blade is decisive for successful results but also the flattening procedure. A filling of the RC requires 6 dosings with the DU, which need to be performed on different positions of the RC to achieve a better initial sample distribution. Tests showed that intermediate flattening after the 4th and 5th dosing lead to the best results. Another parameter that has an impact on the final flatness is the flattening speed with which the PSHS drives the RC underneath the flattening blade. As the nominal speed is 2 °/s, it was discovered that a slower motion of 0.2 °/s leads to much better results. To confirm the flatness during testing, an external 2D laser sensor is used that scans the entire sample while the RC passes underneath it, providing 140.000 measurement points (diameter of 40µm) on a relevant sample surface of 10x10mm within the RC center (see Fig. 16). The suitability of this approached was confirmed by combined testing with the instrument prototypes [5].

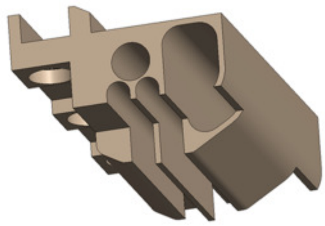

Figure 15. Design of PSHS QM/FM Flattening Blade

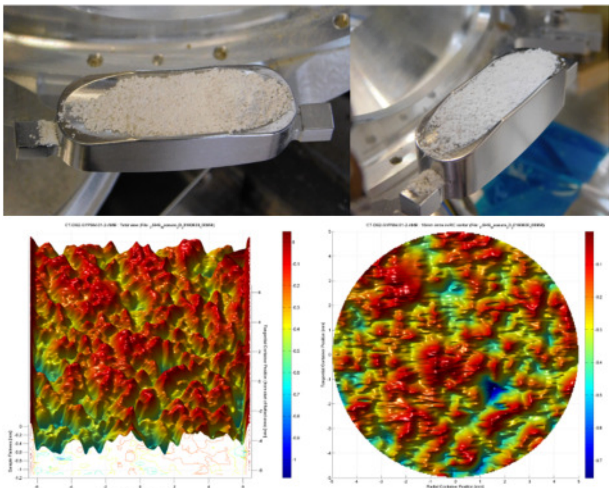

Figure 16. Flattening results of Gypsum from combined PSDDS-PSHS qualification tests with analysis results

With this procedure and blade geometry all relevant sample types could be flattened successfully during breadboard and qualification testing, even when the mechanism was tilted by 10° to simulate the worst case rover attitude. Only one unsuccessful flattening happened during ambient testing of the qualification model. The gypsum sample, already identified as a very critical sample due to its hygroscopic tendency, was mostly removed during the flattening operation (see Fig. 17). This has been traced back to the humidity at the test facility which caused the sample to form large agglomerates as it tends to get extremely sticky. This is a typical case of over-testing and shows the importance of suitable control of test environment and sample. Under Mars-like conditions the sample was successfully flattened.

Figure 17. Ambient flattening of Gypsum (above: successful, below unsuccessful at ambient due to high humidity)

8. CONCLUSION AND OUTLOOK

Extensive testing with elaborated breadboards during early project phases has provided a lot of data and valuable information to optimize the SPDS system regarding sample flow and performance. All four subsystems proved during their qualification campaign their compliance to the sample handling requirements and showed that cross contamination could indeed be minimized to acceptable values.

The following lessons learned were obtained:

- Reference samples to be defined as early as possible covering the entire range of possible properties and behaviour
- Always test both extremes regarding relevant sample properties as early as possible (e.g. hardness)
- Sample preparation and representativeness of test environment are crucial to ensure that test outcomes are not jeopardized by test set-up and conditions
- Sample delivery from external systems has to take place within a specified and guaranteed envelope
- Sample delivery via GSE during mechanism stand-alone testing needs to be carefully assessed, as non-flight like sample delivery can lead to over-testing, as unnecessary problems may occur. Anyhow at one point each sample delivery has to be tested in flight-like configuration (end-to-end)
- Extensive breadboard testing and qualification are crucial for sample handling mechanisms as the occurring effects cannot be predicted by analysis or simulation.
- Results are always subject to statistics as samples will never provide perfect, 100% reproducible behaviour. Therefore mechanisms require to provide robustness and requirements need to account for statistical deviations
- Operational procedures can have a large impact on sample handling performance
- Avoid sliding contacts, or protect them from dust and sample particles
- The shape and material selection of parts in contact with sample are essential to functionality and minimization of cross contamination

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 completely disassembled and after replacement of parts worn out 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.

9. REFERENCES

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