PROGRESS REPORT ON DEVELOPMENT OF THE EXOMARS 2018 SAMPLE PROCESSING AND DISTRIBUTION SUBSYSTEM (SPDS) AND RELATED OHB SAMPLE HANDLING STUDIES

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ABSTRACT

OHB Munich, formerly Kayser-Threde GmbH, has been assuming a leading role in a number of studies and projects addressing space robotics with applications ranging from vision systems, manipulation systems and active space debris removal (e.g. the ADRS and e.Deorbit studies) to mechanical subsystems for the ESA-Roscosmos 2018 ExoMars rover mission. This paper provides a progress report on the on-going development of the Sample Processing and Distribution Subsystem (SPDS) for the 2018 ExoMars rover as well as highlights of related development activities of sample acquisition and handling mechanisms targeted to lunar polar missions through the intended ESA-Roscomos collaboration regarding near-term exploration of the Moon.

The SPDS is being developed by OHB under direct subcontract to TAS-I to supply the scientific instruments of the ExoMars rover with granular Mars rock and soil samples of a specific particle size distribution. This is achieved through a set of mechanisms making up the SPDS which receive the samples from the rover drill, crush, meter (‘dose’) and distribute them. The sequence of operation can be controlled from ground but pre-defined operational sequences are embedded in the Drill and SPDS Control Electronics and will operate the SPDS in a semi-automated way with internal fault protection and llimited flexibility to react to a number of off-nominal situations. Between 2007 and 2013, ever more sophisticated breadboards and engineering models of the SPDS mechanisms have been developed and tested, culminating in the successful “end-to-end” test campaign of breadboards of the mechanisms in correct relative positions in simulated Mars atmosphere and temperature in early 2013.

Since the last ASTRA conference, the SPDS flight design has been finalized, in particular related to solving the incorporation of the static and dynamic pressure seals (the latter with minimized parasitic torque) needed to ensure the required contamination levels within the ExoMars rover analytical laboratory (ALD) which is pressurized until arrival on Mars, and with respect to a Vibration & Shock Mechanism now having become part of the SPDS sample crusher mechanism. Moreover, complex questions on the SPDS mechanisms’ materials coatings driven by both tribology and the need to sustain the ExoMars 2018 sterilisation and ultra cleaning processes have been solved, and the Qualification Model MRR has been fully closed. At the time of this writing, fabrication of the SPDS QM is under way, with integration and test activities now starting.

Since mid 2013, OHB Munich have also been developing the structure of the ExoMars rover analytical laboratory (ALD) (a task delegated to OHB by TAS-I) including the ALD pressurized Ultra Clean Zone (UCZ) surrounding the sample path, on which this paper also provides an update on, including the attendant development of the UCZ pressure relief valve and of the ALD optical windows that likewise are under responsibility of OHB.

OHB are also involved in two different studies related to the planned ESA-Roscomos collaboration on landing missions targeted to lunar polar regions with the objectives of subsurface sampling down to 2 metres depth and analysis of volatile-enriched lunar regolith. In this regard, the paper outlines the OHB contributions towards the ESA-provided elements “subsurface drill” and “analytical instrument” through the studies L-GRASP and ProsPA, respectively.

1. EXOMARS SPDS

1.1. Overview

OHB Munich (formerly Kayser-Threde GmbH), as a subcontractor to Thales-Alenia Space Italia (TAS-I), has been developing the Sample Processing and Distribution Subsystem (SPDS) for the ESA-Roscosmos 2018 ExoMars rover mission since 2007. The SPDS is a set of mechanisms designed to crush and distribute to the 'Pasteur' science instruments Mars subsurface samples acquired by the ExoMars drill. The different mechanisms of the SPDS are distributed among the science instruments inside the Analytical Laboratory Drawer (ALD) contained within the rover structural enclosure. The SPDS consists of the following mechanisms, processing a sample in sequence:

- Core Sample Handling System (CSHS) (consisting of Core Sample Transfer Mechanism CSTM and Blank Sample Dispenser BSD) accepts the samples discharged from the drill and forwards them – exploiting gravity – into the ALD and to the subsequent SPDS mechanism, being the
- Crushing Station (CS), operating as a jaw crusher to comminute granular and massive samples to smaller grain sizes as required by some of the Pasteur science instruments
- Powdered Sample Dosing and Distribution System (PSDDS), being situated below the CS and receiving the sample powder resultant from the crushing; the powder can be dosed by the PSDDS dosing mechanisms and thus dispensed into sample receptacles located below the PSDDS on the
- Powdered Sample Handling System (PSHS) which essentially is a carousel wheel carrying a number of ovens for thermal and chemical processing of the powder samples by the 'Pasteur' MOMA instrument, as well as carrying a 'refillable container' (RC) to present a larger amount of sample powder to close-up observation optical science instruments.

The electronics unit controlling the SPDS – the Drill and SPDS Electronics Unit (DSEU) – is shared with the electronics controlling the ExoMars rover sample acquisition drill and is developed by Selex Electronic Systems (SES).

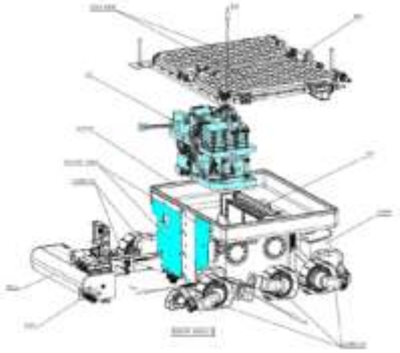

Figure 1. ExoMars rover partially exploded view, showing position of ALD with SPDS within the rover 'bathtub' primary structure (credit: TAS-I)

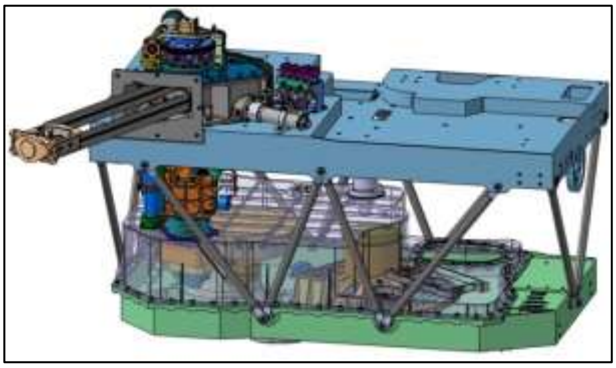

Figure 2. SPDS mechanisms in the ALD

Fig. 1 shows the ALD / SPDS accommodation within the ExoMars rover, and Fig. 2 provides an overview of the SPDS mechanisms as part of the ALD system.

1.2. Concept of the Ultra Clean Zone (UCZ) and associated AIV scenario

The ExoMars 2018 mission is pursuing a very ambitious programme of planetary protection and contamination control for the landed H/W. The main driver for this is to protect the integrity of the scientific measurements to be performed on the subsurface samples acquired by the ExoMars rover drill in order to exclude false positive detection of organics and, possibly, biomolecules by the MOMA instrument.

Principal implementation measures defined by the mission prime TAS-I to ensure the ExoMars 2018 COSPAR Category IVb classification and, specifically, the desired cleanliness levels within the ALD sample path, are:

- A pressurized Ultra Clean Zone (UCZ) enclosing the sample path:
    - Most of the SPDS resides within the UCZ
    - The close-up optical instruments RLS and µOMEGA reside outside the UCZ, viewing the samples through ALD optical windows
    - The SPDS actuators are accommodated outside the UCZ, requiring dynamic seals around the drive shaft
    - Overpressure of the UCZ to the relevant outside environment (Earth, high vacuum during cruise, Mars) is maintained until the ALD door is first opened several days or weeks after landing on Mars, by releasing the CSHS Frangibolt hold-down
- A set of sealed blank samples that can be

released from the CSHS mechanism to assess sample path contamination on Mars
- Sterilisation of ALD sample chain H/W by Dry Heat Microbial Reduction (DHMR)
- Ultra cleaning of the ALD sample chain components and parts in a series of ultrasonic baths and with CO_2 snow
- Final integration of the sterilized and ultra cleaned ALD sample chain H/W in an ISO3 AMC-9 environment at TAS-I (realised through a series of glove boxes referred to as a “glove box train”).

Whereas the responsibility for the planetary protection and contamination control approach for the SPDS and the ALD / UCZ structure rests with TAS-I, OHB are responsible for ensuring that the designs of the SPDS and the ALD / UCZ structure are compatible with the sterilisation and ultra cleaning methods. In this context, a systematic evaluation programme has been carried out between OHB and TAS-I to confirm the final choice of passivation treatment for Al alloy parts which has to be compatible with the sterilisation and cleaning approach whilst respecting the MOMA instrument’s contamination requirements.

As a result of the overall scenario, the SPDS QM and FM programmes both foresee a two-staged approach in which OHB solely performs grade ISO8 integration of the SPDS mechanisms followed by “equipment level” testing.

Following shipment of the SPDS to TAS-I, the steps

- SPDS disassembly
- Sterilisation & ultra cleaning
- SPDS re-integration
- Integration into ALD structure
- ALD-level testing

will occur, closing the SPDS qualification and acceptance.

1.3. SPDS description

The CSHS (Core Sample Handling System) is the initial mechanism for accepting the samples delivered by the ExoMars drill. It is a linear boom-like extension system that transfers the sample (granular or massive core) from the sample discharge port of the drill to a defined position where it is dropped into the Crushing Station. An ALD external door is attached to the mechanism for opening and closing the ALD for sample transfer and which until landing on Mars maintains the UCZ structure internal overpressure through a pre-loaded, static pressure seal.

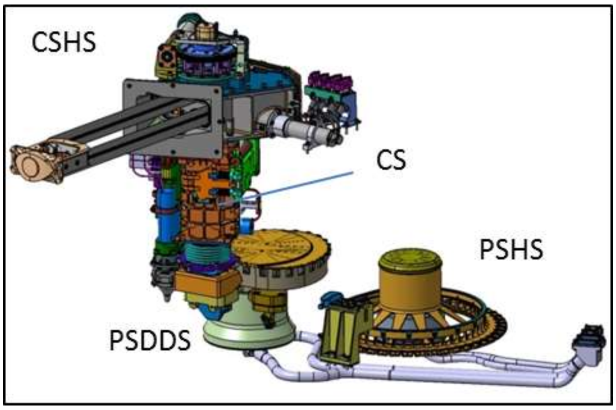

Figure 3. SPDS configuration

A “Blank Sample Dispenser” mechanism (BSD) is part of the CSHS and contains six spherical blank samples of 9 mm diameter to check for contamination in the ALD sample path. The blanks are organic-free and are kept under ultra-clean conditions at all times. This is achieved through encapsulation in ‘blister packages’ consisting of a semi-spherical blister cup and a blister foil. Six separate stamps of the BSD mechanism provide the necessary force for opening the flat breakable blister foil and perform the push-out process of each blister cup. Blank samples can be dispensed by the BSD and transferred into the Crushing Station, further processed by the SPDS and presented to the instruments when desired.

Projected mass of the CSHS flight design is 3.8 kg (including maturity margin).

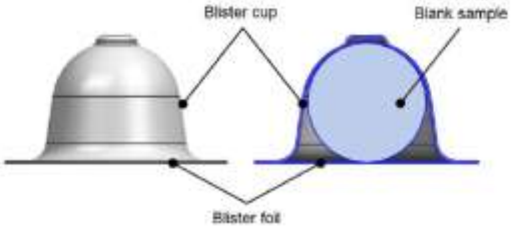

Figure 4. Blister cup with enclosed 9 mm blank samples (from silica fibres)

Figure 5. Dispensing test with blank sample; metal foil at blister package bottom has torn along engraving pattern

The SPDS Crushing Station (CS) is placed beneath the CSHS as part of the UCZ connecting the upper ALD plate via a flexible I/F to the UCZ cover box. The CSHS sample container drops the sample directly into the CS for crushing. The CS is a miniaturized jaw crusher that fulfils the ExoMars requirement for comminuting drill core samples (diameter of 11 mm, length up to 35 mm) to powder fine enough to satisfy the 'Pasteur' analytical instruments' needs. A median grain size of the powder of 250 µm with 90 wt-% falling between 50 and 500 µm is required. The material is crushed between a fixed and a moving metal body (jaw), the latter actuated by an eccentric drive shaft. While milling, the samples fracture into ever smaller pieces. During the crushing, particles, once small enough, fall through a < 1 mm wide gap between the two jaws at the lower end of the crusher, to collect in the hopper of one of two redundant dosing units of the PSDDS mechanism situated below the CS. If a sample is stuck in the crushing chamber the jaws can be opened at their lower end by a de-jamming mechanism to release the uncrushed sample remains.

Based on CS breadboard testing results, it was decided in 2013 to implement a Vibration & Shock Mechanism (VSM) in the CS to mobilize sample fines adhering to the CS crushing jaws, thereby reducing the sample cross contamination. For the VSM, different actuation concepts were considered, and the final design is a mechanism driven by a motorized ball screw compressing a set of springs that accelerate a hammer which in turn impacts on the fixed jaw of the CS. Systematic testing on a breadboard of the VSM was used to finalize the arrangement of metallic damping pads internal to the CS structure that help to concentrate the VSM shock onto the jaw structure, thereby maximising the VSM efficacy.

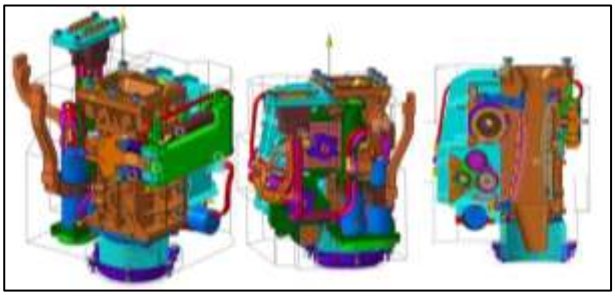

Figure 6. CS / VSM QM / FM design

Projected mass of the CS flight design is 4.1 kg, including the VSM and maturity margin.

Situated underneath the CS, the Powdered Sample Dosing and Distribution System (PSDDS) collects the crushed samples and distributes the sample powder to the receptacles placed on the PSHS sample presentation carousel. Two (redundant) dosing units are mounted to a rotating arm which can position the units either under the Crushing Station or at the sample discharge locations over the PSHS carousel. The dosing units include a hopper facing upwards towards the outlet of the CS crusher, in order to collect sample powder produced by the crusher. Sample powder is stored in the hoppers until dosed in amounts of 0.1 ml per dosing step. The dosing function employs a revolving wheel with hollow pockets of defined volume which are filled with the sample material. Piezo vibrators are used to ease sample discharging and cleaning.

An Alternative Sample Container (ATC) has been added to the PSDDS design that provides sample distribution from the CS to the PSHS sample presentation carousel in the event that the two dosing units become clogged with sample material. The ATC is passively articulated and lacks the capability to meter out defined quantities of sample powder.

To accommodate the rotary movement of the PSDDS rotating arm with the dosing units actuators situated within the moving structure, a flexible harness is part of the PSDDS design and allows for an up to 340° rotation at the specified qualification temperature of -60°C. This flexible harness uses a flex-rigid connection based on Kapton flexes.

Projected mass of the PSDDS flight design is 3.6 kg (including maturity margin).

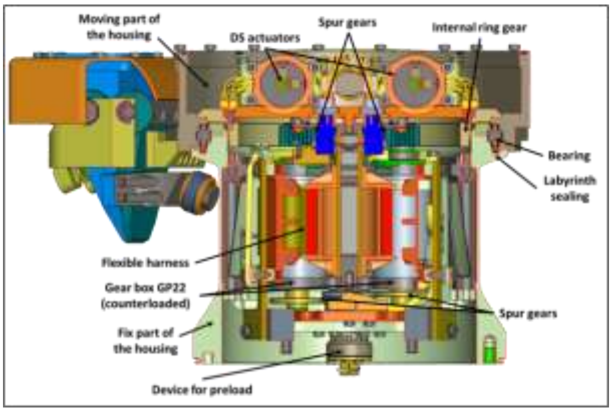

Figure 7. PSDDS QM / FM design

The Powdered Sample Handling System (PSHS) is accommodated next to the PSDDS. The PSHS is a carousel system which transports the powdered sample received from the PSDDS to the ports of the optical instruments of the ALD namely MicrOmega, RLS and MOMA LD-MS. As receptacle for sample presentation for the MicrOmega, RLS and MOMA LD-MS a common refillable sample container (RC) is used. To avoid the need of focusing capabilities of the instruments the PSHS is equipped with a flattening device providing a flat sample surface. After analyzing, the RC disposes the sample with help of a cleaning device.

For provision of sample powder to the MOMA GC-MS, the PSHS carries 35 single-use ovens. These ovens are contributed by MPS (the lead institute for the MOMA instrument) and are sealed by the "Tapping Station" (TS) mechanism (also contributed by MPS).

Quite stringent carousel positioning performance requirements apply, calling for 50 µm positional accuracy and 20 µm resolution. This is achieved by a backlash-free design of the drive mechanism and a rotary encoder of adequate resolution coupled to the mechanism actuator.

Projected mass of the PSHS flight design, including the flattening and cleaning blade assemblies, is 1.6 kg (including maturity margin).

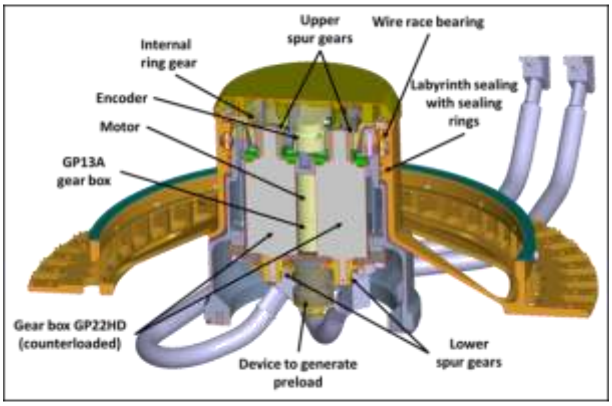

Figure 8. PSHS QM / FM design

All SPDS mechanisms use actuators from Maxon Motor. Maxon have been performing a delta development and qualification programme specifically for ExoMars actuators as needed for the rover mobility mechanisms, the sampling drill, the SPDS as well as a variety of other mechanisms on the landed system. For the SPDS, several additional, specific modifications are implemented. Of note is the dedicated develoment of a rotary encoder by Maxon as needed for some of the SPDS actuators and the rover mobility actuators. Liquid lubrication of the bearings and gears has been selected, using Braycote 601EF grease (used previously also in Maxon actuators on the Beagle 2 Mars lander on ESA's Mars Express mission).

Figure 9. Crushing Station de-jamming mechanism QM actuator from Maxon Motor

The SPDS AIV concept assumes the feasibility of integration and assembling the mechanisms considering the very stringent cleanliness requirements of the UCZ (ISO3 AMC-9). Therefore, the mechanism concepts of the CSHS, CS, PSDDS-Positioner and PSHS allow the integration of the actuators, sensors and corresponding harnesses after closure of the UCZ in the glove boxes at TAS-I (see section 1.2). The only drive train that has to be assembled inside the UCZ is the one for the PSDDS dosing units due to the envelope constraints.

1.4. Pressure seals

One main requirement for the SPDS system is to create and maintain the ALD ultra clean zone (UCZ) which is at overpressure until after landing on Mars (see section 1.2). Relevant SPDS requirements state an allowed leakage rate of $5*10^{-6}$ std.cc/sec He at an UCZ overpressure of 0.1 bar.

Besides static seals, the UCZ requires dynamic seals to place the actuators, gears and bearings outside of the UCZ. Also the need for an ALD door (being part of the CSHS sample container) that can be opened after landing on Mars requires a dedicated sealing.

Following trade-off's, metallic C- and O-ring seals from Inconel have been selected by OHB as the static pressure seals in the SPDS / ALD system. Dynamic – i.e., rotary – seals are grease seals, with the low temperature grease (Braycote 601EF as also used in the SPDS actuators) held in place by metallic C- and O-rings with loose fit.

In a dedicated test programme performed at OHB in 2014, leak rates for all seal types used in the SPDS design as well as parasitic torques from the dynamic seals have been measured at temperature, confirming the assumptions made during the design phase.

Figure 10. Breadboard testing of ALD door with metal C-ring seal (May 2014)

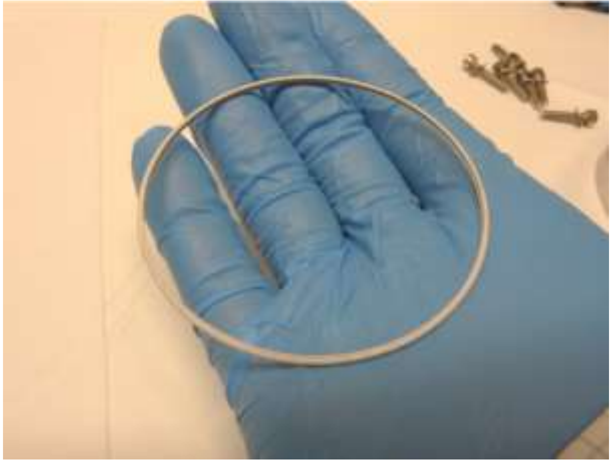

Figure 11 : One of the Inconel C-rings used in the SPDS as a static seal

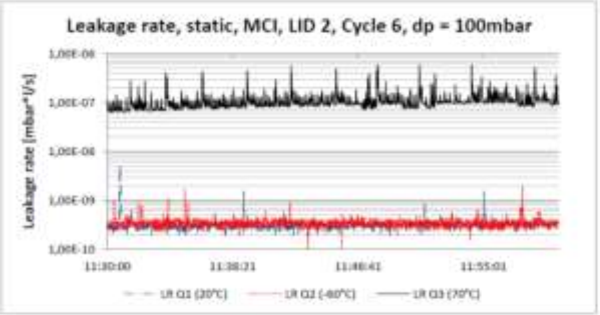

Figure 12 : Measured leak rate of MCI lid 2 seal during 2014 test campaign, for different temperatures and a delta pressure of 0.1 bar (nominal UCZ overpressure)

1.5. Effect of Mars gravity

The SPDS mechanisms rely on the action of gravity in the flow of the granular samples from one SPDS mechanism to the next. To capture and understand the effects of reduced gravity (Mars g vs. Earth g) on the performance of the SPDS, the SPDS development has been relying on a combination of testing on parabolic flights and numerical simulations. In June 2011, under contract with ESA, Kayser-Threde performed a parabolic flight campaign to test the behaviour of the dosing hoppers of the PSDDS dosing unit under Martian gravity. The aim was to verify the performance requirements of the SPDS Dosing Station at 1/3 Earth gravity (corresponding to conditions on Mars), to verify the quantity of sample dosed (throughput), to assess cross-contamination between successive samples and to assess the influence of vibration (the dosing station being equipped with piezo vibrators to assist in powder flow).

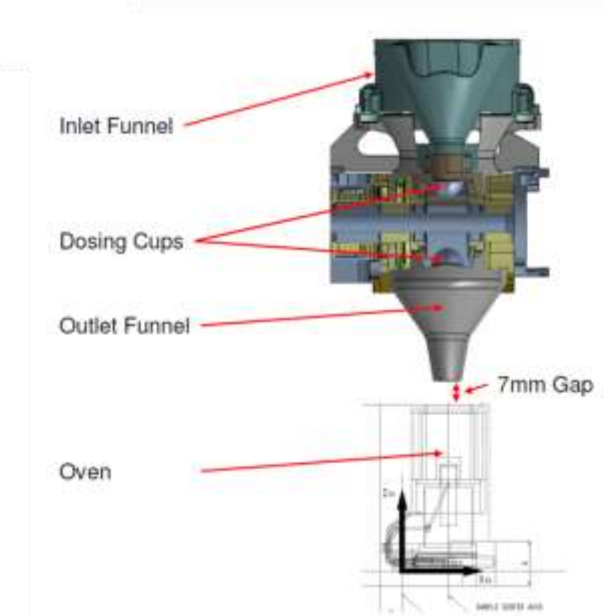

Figure 13. Side view of relative position of PSDDS dosing station and PSHS oven (below). Inlet and outlet funnels of dosing station are labelled. Gravity vector points downwards

In parallel, a numerical simulation effort has been started in late 2011 together with the University of Leeds (UK) to model mechanism / sample interaction effects as a function of gravity. The modelling approach chosen was the Discrete Element Method (DEM). A subsequent parabolic flight campaign was run in December 2012 by the University of Munich (TUM / LRT), flying a series of different 2D shapes of the PSDDS Dosing Station hoppers at simulated Mars and lunar gravity, with the sample holders and powders exposed to Mars atmospheric pressure [3].

Simulation and testing were shown to agree in recommending a slight design change for the PSDDS inlet hoppers in enlarging the outlet throat diameter to enhance mass flow at Mars gravity for cohesive materials which was subsequently implemented in the design.

Recently, higher fidelity simulations on the sample flow through the inlet hopper have been performed (again by the University of Leeds) that incorporate measurements of inter-particle forces using Atomic Force Microscopy (AFM) and Colloidal Probe Microscopy (CPM), on a set of SPDS reference samples processed with the SPDS Crushing Station Engineering Model (EM) and enriched with different moisture contents (affecting cohesion). The measurements on inter-particle forces show a relatively higher level of cohesion for moist samples than for dry ones, as expected. The measured forces were used in a set of 3-dimensional DEM simulations of the powder flow through the dosing mechanism inlet hopper, in place of force *estimates* that had been used in the original simulations in 2012. Simulations were done for 8 different soils (on which inter-particle forces had been measured), and for Mars gravity. For each of the soils, not only the measured internal adhesion forces were applied but also their measured particle size distributions were reflected in the particle (spherical) models within the DEM simulation.

In Figure 14, flow rates at Mars gravity are shown for all of 8 samples simulated, but normalized to the flow rate of sample "S1" (fine sand and Montmorrilonite mixture, crushed) which in the AFM / CPM measurements was found to be relatively cohesionless.

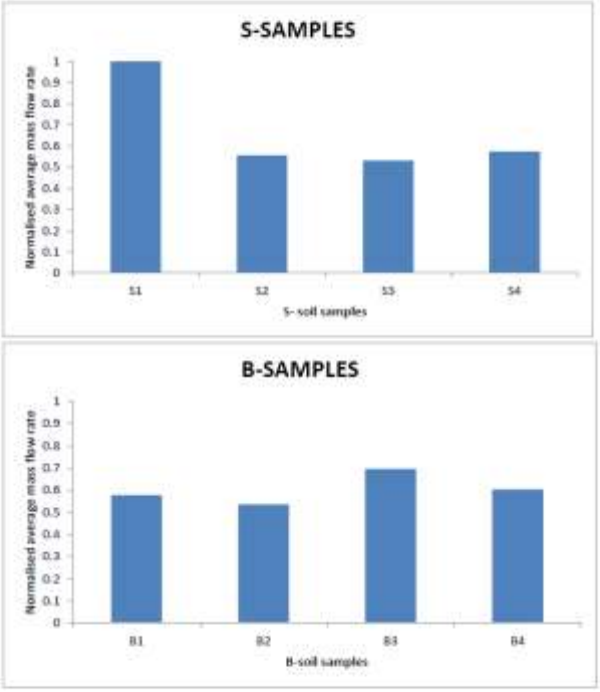

Figure 14. Flow rates through the PSDDS inlet hopper during sample dosing, at Mars gravity, of the 8 simulated samples. Flow rate is normalised to that of sample "S1" (fine sand and Montmorrilonite mixture, crushed)

Overall, the simulation runs confirm adequate sample flow through the DS inlet hopper at Mars gravity with the finally selected (in the design) outlet throat diameter even with no piezo agitation.

1.6. SPDS control

Control of the SPDS is by the ExoMars Drill and SPDS Electronics Unit (DSEU) which is shared with the sample acquisition drill and is developed by Selex Electronic Systems (SES).

During the Mars surface mission of the ExoMars rover, command sequences will typically be radiated from Earth to the rover once per Mars day ('Sol'). Data may be relayed up to twice per Sol from the rover to Earth, via one or more Mars orbiters passing over the landing site and offering UHF relay services to assets on the surface. The ExoMars rover, like previous and current Mars rovers by NASA, will thus extensively rely on on board autonomy to control housekeeping and communications with Earth, mobility to a designated (by operators on Earth) drive target, scientific remote sensing operations, acquisition of surface and subsurface samples by the drill, transfer of samples into the ALD and their mechanical processing by the SPDS and, finally, analysis of the resultant sample powders by the 'Pasteur' instruments in the ALD.

Some SPDS acitivities require intervention from operators on Earth before committing to a subsequent step in sample processing: currently, these are:

- Initiation of sample crushing by the CS: prior to authorizing this activity, imaging of the sample (by the rover mast-mounted cameras) residing in the CSHS sample container following its discharge from the drill head needs to be assessed in the gound control centre to verify the actual transfer of a sample and its physical appearance; at the time of image assessment, the sample will already have fallen into the CS and is therefore already protected from Mars surface UV, radiation and the surface temperature cycle; if assessment suggests not to process the sample, the CS can be commanded to move to the 'dejamming' configuration to permit the sample to exit the CS and to drop into a 'waste container'
- Initiation of dosing of sample powder following crushing in the CS: prior to authorizing this activity, engineering data from the CS crushing operation needs to be assessed in the gound control centre to verify the adequate extent of sample comminution; if deemed insufficient, a new period of crushing may be commanded (the nominal duration of crushing operation for a given sample is not to exceed 2 h)

- Initiation of a MOMA pyrolysis sequence on sample powder dosed into one of the MOMA ovens: prior to authorizing this activity, imaging of the respective oven by the µ-OMEGA science instrument in the ALD sitting on the common instrument 'working circle', following powder dosing into the oven, needs to be assessed in the ground control centre to verify presence of a sample in the oven (such as not to waste one of the single-use ovens in case of failed sample delivery).

Actual SPDS mechanisms operations, such as performing a crushing run, dosing *n* 0.1 ml aliquots of sample powder or positioning the PSHS carousel with a filled RC sample tray or a filled MOMA oven to a particular position, are then performed autonomously. To do this, the SPDS design includes a number of sensors, such as

- Rotary encoders
- Potentiometers
- Hall sensors (as proximity sensor to indicate 'end stop').

Early testing of the H/W-S/W interface between the SPDS and the DSEU control electronics for the SPDS (developed by SES) in late 2013 and early 2014 has been another risk reduction activity successfully mastered in the project by OHB: the EM of the DSEU running an early version of the DSEU flight S/W was used to run the SPDS end-to-end ("E2E") system which for that test run had included representative feedback sensors in the mechanisms breadboards / Engineering Models. Development of the SPDS control S/W running on the DSEU is based on SPDS control algorithms defined by OHB.

Figure 15. Testing of SPDS E2E system with DSEU control electronics in early 2014 at OHB

1.7. Results from SPDS components testing and SPDS End-to-End (E2E) testing

Development of the SPDS has been very H/W-focused, involving several generations of breadboards / Engineering Models since 2007. Using those early models, not only mechanisms-level testing has been successfully performed but also testing as an "end-to-end" (E2E) system where the different SPDS mechanisms had been linked together in their correct relative positions.

In particular, for the E2E testing performed in early 2013, the SPDS breadboards / Engineering Models had been modified to be suitable with Mars environment testing down to -60 C temperature which is the SPDS lower qualification temperature. E2E testing was initially conducted at ambient conditions, processing successfully all of the ExoMars reference samples. Subsequently, E2E testing was performed successfully at simulated Mars atmosphere and temperature conditions using the Aarhus Mars simulation facility in Denmark.

Results of the E2E testing were described at the last ASTRA meeting (ASTRA 2013) [1].

Figure 16. E2E ‚phase 2' testing in Mars environmental conditions: scene from March 2013 at Aarhus test facility, E2E test set-up is visible on chamber bottomplate

Apart from SPDS mechanisms breadboard and E2E test campaigns, also a number of component test activities have been successfully performed by Kayser-Threde (now OHB) to complete the SPDS technology development and to reduce development risk; this includes:

- ALD door seal (being part of the CSHS mechanism) breadboard testing: see section 1.4
- SPDS static & dynamic seals testing: see section 1.4
- Crushing Station (CS) Vibration and Shock Mechanism (VSM) breadboard testing
- CSHS Blank Sample Dispenser: mechanical testing of blister package dispensing.

1.8. ALD / UCZ structure, pressure relief valve and optical windows

Since mid 2013, OHB Munich have also been developing the structure of the ExoMars rover analytical laboratory (ALD) (a task delegated to OHB by TAS-I) including the ALD pressurized Ultra Clean Zone (UCZ) surrounding the sample path.

The ALD / UCZ structure conceptual design had been developed by TAS-I and was then detailed by OHB. Two main panels – from Al alloy – are interconnected by composite struts, carriying not only the SPDS mechanisms but also the “Pasteur” instruments, the DSEU control electronics for the ALD as well as ALD thermal control H/W. A hood interfaces with the ALD structure lower platform (also referred to as the “baseplate”) and forms the principal enclosure of the UCZ. Inside it, the PSDDS and PSHS subsystems of the SPDS are housed, and a long pressure seal – again an Inconel C-ring – ensures pressure tightness between the hood (the “UCZ cover”) and the baseplate, as part of the overpressure UCZ concept.

The structure also accommodates the iso-mount interfaces by which the ALD system – amounting to ~45 kg in mass – interfaces with the ExoMars rover primary structure.

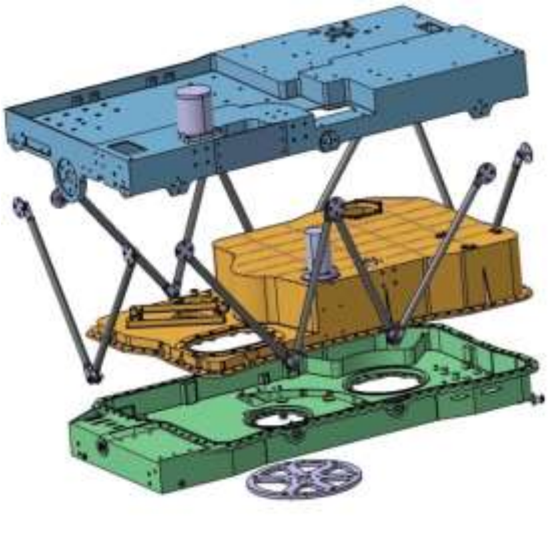

Figure 17. Overview of ALD / UCZ structure: top: “upper plate”, bottom: “baseplate”, centre: “UCZ cover”; struts interconnect upper plate and baseplate

Not only has the ALD / UCZ structure design been driven by mass, envelope, strength and pressure tightness constraints but also by severe shape integrity requirements as the optical instruments MicrOmega and RLS pose demanding sample positioning requirements, the achievement of which also relies on the behaviour of the structure.

Figure 18. Fit check of UCZ pressure seal (Inconel C-ring type) on baseplate of STM of ALD structure, April 2015

A critical element of the ALD / UCZ structure is the UCZ pressure relief valve which is mounted to the UCZ cover. It serves to control the pressure of the filling gas (Argon) inside the UCZ. The valve maintains a constant overpressure of nominally 100 mbar (± 20%) in the enclosed volume of the UCZ w.r.t. the external environment, i.e. the environment outside the ALD / UCZ, during ground operations and in space until first opening of the ALD / UCZ door after landing on Mars. This is to ensure no biological contamination can enter the UCZ which would falsify the search for organics in the Martian samples. The valve is operating purely passively, simply by way of a spring-driven orifice. Without the valve, the UCZ structurally would have to be sized for an overpressure of 1.1 bar (instead of 0.2 bar including margin) which would have prohibitively driven up the structure mass.

Since the SPDS sample handling takes place inside the ultra-clean zone (UCZ) while the optical “Pasteur” instruments MicrOmega and RLS are located outside of the UCZ, two sealed optical windows are integrated in the structure – specifically in the UCZ cover – in order to allow the analysis of the samples. These windows are part of the ALD structure system and are also developed by OHB. Each window consists of 2 main parts that are soldered together: an optically transmissive substrate (the window ‘glass’), and a metal carrier. The carrier provides the holding frame by means of which the window is attached to the ALD structure. Between carrier and ALD structure, a metallic seal ring provides leakage tightness and electrical connection (required for antistatic grounding). The optical requirements on the windows and the soldering process between substrate and carrier result in a complex stack of coatings to be applied.

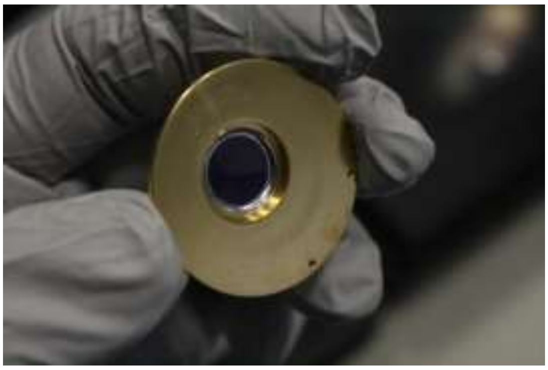

Figure 19: Development Model version of the ALD window for MicrOmega (identical in design to QM / FM window), prior to successful shock testing in late 2014

1.9. Criticalities mastered in the design

The development of the SPDS and of the ALD / UCZ structure had to go through a variety of design challenges, in particular related to the QM / FM designs produced over the past 2 years. This was principally related to the following aspects:

- Conflicting requirements related to surface treatments and properties of the parts:
    - Required compatibility with the ExoMars-specific cleaning and sterilisation processes for planetary protection (PP) (calling for careful selection of mechanical parts passivation that does not degrade as a result of the PP activities; also calling for very stringent surface roughnesses for parts touching samples)
    - Required hardness of tribological surfaces of the SPDS mechanisms that may be conflicting with the PP-related requirements
    -
- Manufacturability of SPDS parts – of mostly very unusual shape – with tight tolerance requirements to ensure mechanism functionaility across the specified temperature range
- Choice of the type of pressure seals (both static and dynamic).

1.10. Programmatic status

Since the last ASTRA meeting 2 years ago, the flight design of the SPDS has been performed, and a PDR / CDR held and closed. Subsequently, the MRR has been held for build of the SPDS QM system which is the first build of the flight design. At this time, manufacture of the QM parts is fully under way and Long Lead Items procurement for the QM is complete. The PSHS QM is the first of the SPDS QM mechanisms to be integrated, with integration starting this month (May 2015). Over the subsequent 3 months, the remaining 3 SPDS mechanisms will follow. In a staggered sequence, qualification testing of the 4 mechanisms will be performed at OHB, with subsequent shipment of the SPDS QM to TAS-I.

Since mid 2013, the preliminary and then the flight design of the ALD / UCZ structure has been performed by OHB and a PDR / CDR held and closed. The first model of the structure being built at this time is the STM on which the mechanical qualification will be performed. The STM is followed shortly thereafter by the QM version.

At TAS-I, ALD system-level testing of the QM ALD will be carried out after the SPDS QM has been sterilized and ultra-cleaned and integrated into the ALD QM structure.

FM build is to commence by August 2015.

2. LUNAR APPLICATIONS

Several space agencies are preparing a new round of robotic landing missions to the Moon, with particular focus on the polar regions in pursuit of volatiles now confirmed by a variety of remote sensing techniques and the LCROSS impactor experiment [4,5]. In particular, Roscosmos has defined a series of lunar landing and sample return missions – Luna-Glob / Luna-Resurs / Luna Sample Return – targeted to the lunar poles. Since 2013, ESA and Roscosmos have been in a collaboration to define possible contributions by ESA to this new programme. Current plans envisage an ESA-controlled development of a subsurface sampling drill suitable for icy regolith and an analytical instrument for analysis of the acquired samples. At a polar site, lunar regolith accessible to a robotic lander may include crystalline ices as a volatile component admixed in the regolith.

If a sample handling and processing system based on the heritage of the ExoMars SPDS developed by OHB were to be considered for such an application, likely design modifications are associated with manipulation and handling of ‘icy’ samples and their protection from premature loss of their volatile contents. To this effect, the end-to-end (E2E) testing with the SPDS breadboards (see section 1.8) did include several regolith analogs that were mixed with water and subsequently frozen to be processed by the SPDS in a simulated Mars environment. Accordingly, samples with < 20 % water ice content presented no issues to the system, with the sample being ground successfully to the desired grain sizes and dosed for observation and analysis by the science instruments.

ESA awarded the L-GRASP TRP contract to an industrial team led by SES, with OHB Munich as a subcontractor. L-GRASP, ‘Lunar Generic Regolith Acquisition / Sampling Paw’, has traded off concepts for a lunar regolith sampling device as part of a rotary-percussive drill compatible with a lunar polar site and subsurface access down to 2 m of depth, reflecting the requirements of the planned Russian LUNA 27 lander mission. OHB has interacted with lunar scientists to propose a suitable icy lunar regolith analogue which was subsequently produced and characterized by dedicated laboratory experiments. In parallel, the L-GRASP mechanical concept was selected and the corresponding breadboard designed by SES. Testing in the icy lunar soil simulant is to begin in June.

Figure 20. Icy regolith sample following strength testing by penetrometer

Another lunar-related study in which OHB Munich is involved is ProsPA (Lunar Polar Prospecting: Processing and Analysis), funded through the ESA GSP. This study is led by the Open University (UK) and investigates the analytical instrument to be part of the prospective ESA contribution to the Russian LUNA 27 mission, i.e. the instrument that would analyse the samples acquired by the subsurface drill. Here, OHB are responsible for the “Sample Inlet System” (SIS) which – similar to the ExoMars SPDS PSHS carousel – carries ovens to be sequentially filled with samples. The SIS also features the oven sealing mechanism, likewise under OHB responsibility. Because of more severe oven leak rate requirements in comparison to previous instruments developed for Mars missions and for Rosetta lander Philae, a knife edge seal has been adopted for the ovens. To confirm the assumed sealing forces to be applied by the SIS oven sealing mechanism, a test set-up has been designed by OHB simulating the sealing arrangement. Testing is currently on-going, in parallel to performing the preliminary mechanical design of the SIS.

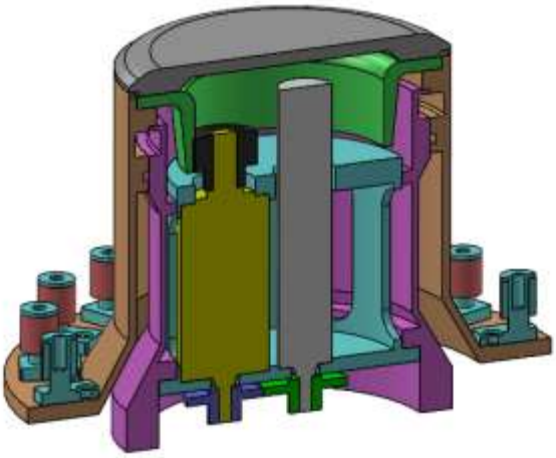

Figure 21. Conceptual design of SIS carousel wheel (inherited from SPDS PSHS)

Figure 21. Test set-up at OHB for measuring ProsPA oven sealing forces and leak rates

3. Conclusions

Space Robotics is a major line of projects at OHB Munich, comprising planetary exploration robotics and orbital robotics. This paper describes our on-going activities related to automated sample handling and sample distribution for planetary landing, roving and sample return missions. The major current project in this area is development of the Sample Processing and Distribution Subsystem (SPDS) for the ESA-Roscosmos

ExoMars rover mission which now is in the production phase of the SPDS Qualification Models. Moreover, OHB Munich are involved in the L-GRASP lunar polar regolith sampling device study for ESA and the ProsPA lunar icy regolith analysis instrument study.

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