# DEVELOPMENT AND GROUND TEST CAMPAIGN OF A SAMPLING TOOL MECHANISM FOR LOW GRAVITY BODIES

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ABSTRACT

The purpose of this activity was to conceive, develop and test a sampling tool mechanism to collect at least 100 g of regolith from a low gravity body. This paper covers the trade-off done between different technologies and the design made for the selected concept. It also describes the extensive sampling test campaign done under laboratory conditions and the lessons learnt. This activity was conducted as part of ESA's Mars Robotic Exploration technology development programme. Next phase includes testing in micro-g conditions on a parabolic flight.

The resulting technology can be applied to several future ESA missions in which collecting and returning regolith samples back to Earth for scientific analysis is envisaged. A mission candidate for such technology is Phobos Sample Return mission (former Phootprint Sampler Return).

## 1. INTRODUCTION

### 1.1. Background

The objective of the activity was to carry out a rigorous engineering assessment in order to perform a trade-off of several sampling mechanism concepts and select the most adequate design to collect at least 100 g of regolith from a low gravity body (e. g. a Mars moon or a Near - Earth asteroid). A prototype for test under laboratory and micro-g conditions on a parabolic flight was designed, manufactured and assembled.

The sampling strategy and hardware system must be robust and compatible with potentially unexpected environmental conditions. The resulting technology can be applied to several future missions planned by ESA in which it is envisaged to collect a sample of regolith and carry it back to Earth for scientific analysis. Two missions were taken as representative to define the requirements for the sampling tool mechanism: MarcoPolo-R and Phootprint Sample Return Mission.

At the end the activity was redirected towards the Phobos/Phootprint Sample Return mission because Marco Polo R was not selected for implementation in ESA's medium sized mission program (Cosmic Vision M3).

The main goal of the MarcoPolo-R mission was to return unaltered Near Earth Asteroid material for detailed analysis in ground-based laboratories.

Phobos Sample Return Mission will return a sample from the Mars moon Phobos. It will be launched in 2024.The spacecraft composite is made of three main elements: a Lander, an Earth return vehicle and the Earth re-entry capsule.

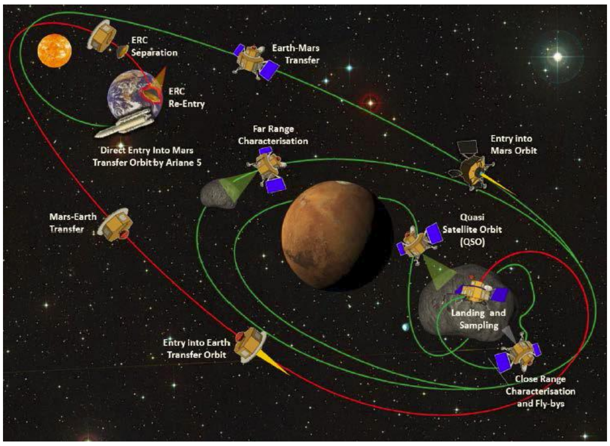


Figure 1. Phootprint Mission profile (Credits ESA)

## 2. SYSTEM OVERVIEW

### 2.1. Requirements

The following sampling procedures were baselined for this activity:

In the touch and go sample acquisition approach, the S/C descends to the surface with to the largest extent limited residual vertical and lateral velocities. During a very short period (~2-3 s), the sampling mechanism touches the surface and collects regolith.

In the landing and long duration sampling approach, the Lander descents towards the surface and performs a soft landing. Eventually, the spacecraft will stay on the surface for a number of day/night cycles to allow iterations with the ground team to select a sampling spot. During this time, a robotic arm will position and move the sampling tool onto the surface. If the soil is not appropriate for sampling, the robotic arm can be repositioned to another location.

For both scenarios: after positive confirmation that a sufficient amount of sample material has been collected, the sample canister is inserted by means of a transfer system, into the Earth Re-entry Capsule, ERC.

The detailed design or breadboarding of the transfer and containment system on the ERC was out of the scope of the activity, but the constraints/interfaces associated to it were strongly taken into account when producing the design of the sampling tool itself.

For MarcoPolo-R mission, the force induced along the z-axis during the touch & go approach was minimized by the flexibility of the boom-flexible joint assembly. It shall be limited to 50 N. However, as a worst case scenario a lateral velocity along x-axis (parallel to the surface) of max. 5cm/s had to be considered

In Phobos Sample Return Mission, the sampling force is limited to 20N (tbc). The robotic arm will have the possibility to move the sampling tool within an area of 1 $m^2$ (tbc) with lateral and vertical velocity to allow efficient sampling.

**2.2.** Technology Trade-off

A trade-off between candidate technologies was made taking into account the state of the art in sampling technologies and the requirements applicable to the development.

Apart from brushes, solutions as scoops, gas jets, augers and punches were studied and ranked taking into account criteria such as: efficiency in collection of particle sizes from 1µm to 3 cm, simplicity of operation, mass, mass transferred to the ERC, compatibility of the design with the insertion of the sample canister into the ERC, robustness against lateral velocity during sampling and local surface slope, compatibility of the technology with different sampling durations, sample contamination and capability of the sampling tool to maintain the sampled soil inside the sample canister.

As a result of the trade-off done, the brush sampling technology was identified as the most promising technology to collect samples in a low gravity body.

## 3. MECHANICAL STRUCTURE

The sampling tool consists of a brush-wheel mechanism with 3 rollers forming an angle of 120º between each other and actuated by one motor each. When the bristles of the brushes touch the terrain the regolith particles are dragged, lifted and driven into the sample canister, which is placed in the upper-central side of the main structure. The internal geometry of the sample canister and a closing door mechanism prevent the regolith particles to escape the canister.


Figure 2. AVS Sampling Tool Mechanism Breadboard

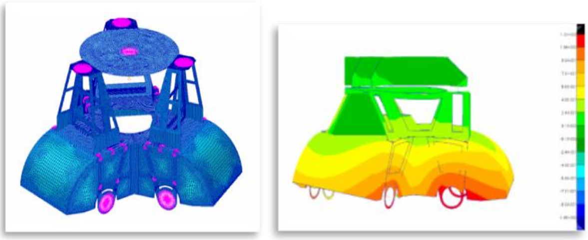

Figure 3. Sampling Tool Mechanism Breadboard; FEM.

After the sample collection, three sequential disengagement devices allow to release the sample canister and insert it into the ERC. These disengagement concepts have been included in the design but were not implemented in the breadboard.

The transfer mechanism to the ERC was not within the scope of the present activity. Nevertheless, the constraints and interfaces associated to it have been strongly taken into account as they have direct impact on the sampling tool design.

**3.1.** Brushes

The brush optimisation was of essential importance for a successful design of the mechanism. One of the advantages of this solution is its versatility, as it can be designed with different type of bristles (different materials, stiffness and number). The distribution of them can be optimised to reach the best performance.

Supported by an early test campaign, the following parameters were studied in detail: row type, diameter, length, material, number of rows, and number of bristles per row.

On the other hand, the number of brushes to be implemented was studied. The use of only one brush was not considered optimal as it would generate torsion loads that would have to be balanced by the rest of the mechanism and would also be transmitted to the other systems (joint, boom/arm and spacecraft). In a 2-brush configuration the inertias generated are cancelled out by the motors. The collecting process is also more efficient. In a three motors configuration the inertia balancing, redundancy and also the acquisition efficiency is optimised while reducing the negative effect of an eventual lateral velocity with respect to the asteroid/moon surface during the sampling process.

### **3.2.** Sample canister

The sample canister consists of Al7075 deposit with a conical surface to guide it into the ERC. In the canister upper side, a conical geometry was also designed as part of the deposit HDRM. This approach reduces the lateral loads in the release device.

The sample canister overall volume is ø135 mm x 120mm. In fact, the volume that would be inserted into the ERC, is the one corresponding to the deposit plus a volume margin in case of door blocking by a regolith particle with a reference dimension of 3 cm. In the breadboard version a transparent part to allow watching inside of the deposit and a tube to allow the canister emptying was included.

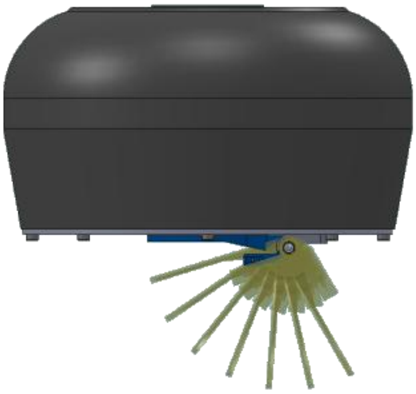

Figure 4. Sample Canister

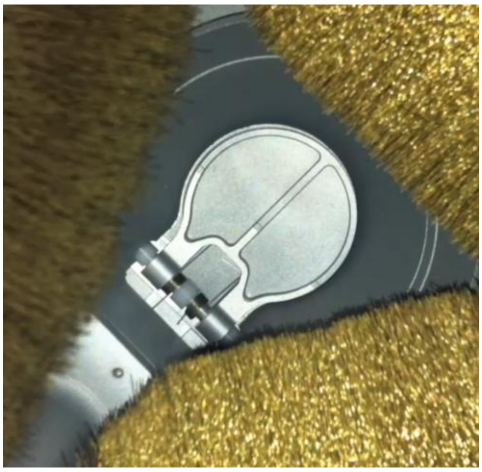

Figure 5. Sample Canister door mechanism

## **4.** TEST CAMPAIGN

A test campaign with an early breadboard was essential in the motor definition process and, in particular, bristle material and configuration, number of rows, insertion cone geometry, and motor torque were established.

Once the final breadboard was designed, manufactured and assembled, a test campaign representative of the sampling sequence was performed. The parameters related to the representative sampling sequence were identified and reproduced by the test rig in order to validate the sampling tool mechanism functionality and to verify the compliance with the requirements. The values selected for such parameters which combination lead to the test matrix, were:

- Rotation rate of the brushes (500-1000rpm)
- Penetration depths (5-48mm)
- Sampling time (0.4s-300s)
- Horizontal velocity (0 to 10 cm/s)
- Vertical velocity (0 to 5 cm/s)
- Orientation (0º, 60º)
- Slope (0º, 10º)
- Sampling time (0.4-300s)

More than 300 representative sampling sequences were performed. Combining all the parameters listed above the different case studies were carried out and compared, selecting the corresponding parameters to reproduce a wide variety of sampling conditions.

### **4.1.** Test rig

A test rig was designed to perform the ground test campaign for sampling tool mechanisms in laboratory conditions. The test rig includes two automated linear stages, one vertical and one horizontal, and one manual slope regulator. It also includes a load cell to measure forces in vertical axis. Control system and data acquisition are designed in Labview environment.

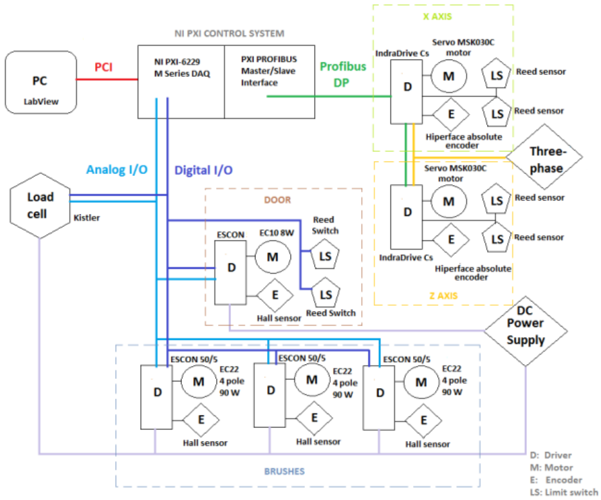


Figure 6. Control and data acquisition of Ground test rig

The automated movement of the Tx and Tz is achieved with two motorized linear slides. Each of these linear slides includes servomotors and absolute encoders in order to accurately control their position and velocity.

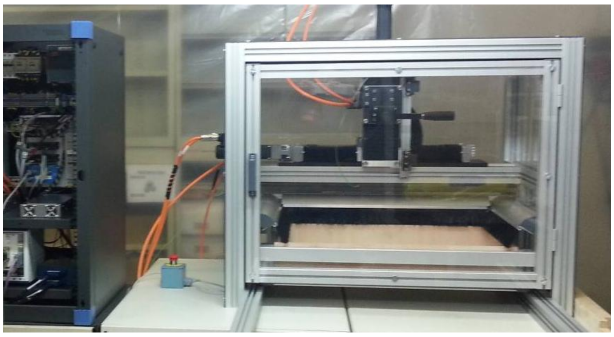

Figure 7. Ground test rig

One rotation angle of freedom can be manually adjusted in order to be able to test the functionality of the sampling tool when the local surface topography presents a slope.

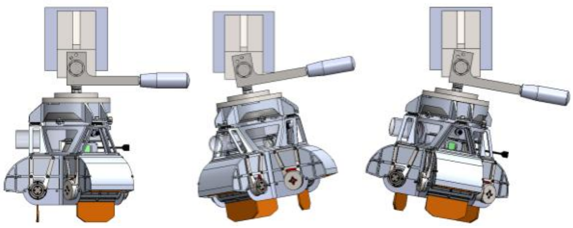

Figure 8. Slope manually adjustable in the test rig; available positions: 0º, 10º and -10º

A soil container was included to accommodate the regolith simulant.

Due to the weight of the container with the soil inside, it is difficult to manipulate the crate to level or change the regolith after a sampling process, thus, a wheeled structure was included in order to place the soil-filled-crate on it and to easily insert and extract the container into the working zone.

## **4.2.** Regolith Simulant

Although an asteroidal regolith has never been investigated by in-situ measurement, a reasonable assumption on the physical properties can be made. This figure is derived from remote observations of asteroid surfaces, analysis of meteoritic regolith breccias.

- Bulk density (sample material) 1-2.2g/cm3.
- Compressive strength applicable to individual pebbles: 0.3 up to 30 MPa.
- Intra particle cohesion: 0.1-5kPa.
- Shape: Any (e.g. Rounded, tabular, elongated)
- Angle of friction: 15º-40º.
- Grain size: from 1 micron up to 3cm

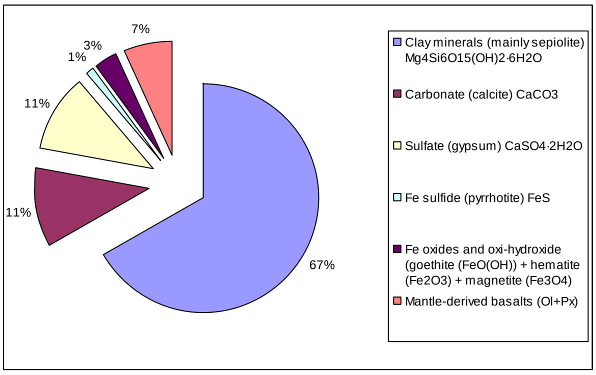


Figure 9 Regolith simulant composition circular chart

Five sets of soils were used during the ground test campaign. They consist of sand, sepiolite in different fraction configurations, and a customised regolith simulant. This simulant not only fulfilled the properties of an asteroidal regolith but also trying to match the mineralogical make-up (and mineralogical and geochemical processes) which were identified in CI Chondrites, was custom made and used during the test campaign.

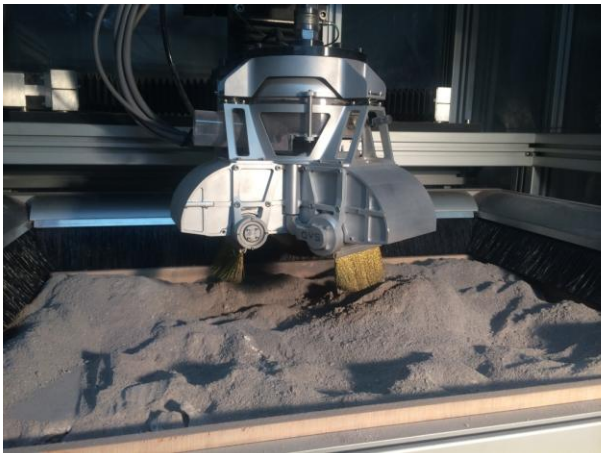

Figure 10. Sampling Tool in test rig with asteroidal regolith simulant

### 4.3. Test results

During the test campaign the transmitted force, motors torque and mass collected in the sample were measured and recorded. Good performances were obtained for the two sampling scenarios.

More than required (100g) amount of soil can be sampled for the specified volume and mass constraints when a proper combination of sampling parameters (rpm, sampling depth, velocity, etc) is selected.

Figure 11. 300g of sampled regolith simulant (sepiolite from 1micron to 3cm)

The behaviour of the system with each set is very particular and different from the rest of soils. Therefore, it is very important to define the soil characteristics as close as possible to the real one. That way, it would be possible to choose the combination of parameters that would lead to the most efficient sampling for those conditions.

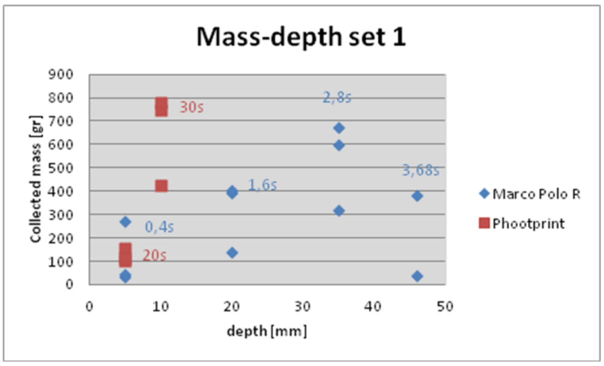


Figure 12. Collected mass versus depth comparison for Marco PoloR and Phootprint

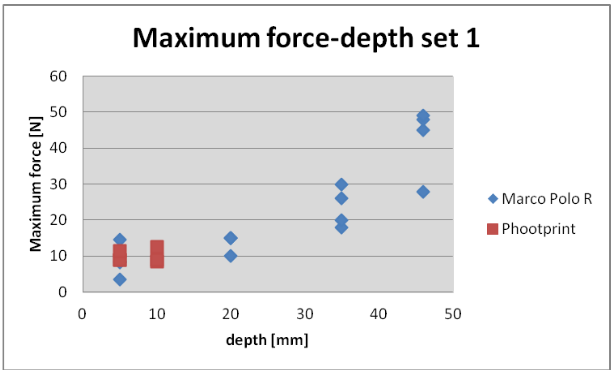


Figure 13. Maximum force versus depth comparison for Marco PoloR and Phootprint

The current reading from the motors provides good insight into the sampling conditions and process as such. This could be taken into account as a method for verification of the sampling success.

## 5. CONCLUSIONS

A Sampling Tool Mechanism able to collect more than 100g of soil from a low gravity body has been developed. The technology is applicable to the next Phobos Sample Return Mission.

The mechanism has been designed, and its functionality has been validated by performing a ground test campaign in laboratory conditions. The weight of the mass sampled, the required amount of soil sampled in the specified time, and the capability of the breadboard to sample the required amount of mass with the defined velocity and slope conditions have been successfully verified. Good performances have been obtained for two sampling scenarios. As a result, a TRL 4 level has been reached with this Breadboard

The main characteristic of the mechanism is its versatility to different mission scenarios like touch & go and full landing with robotic arm deployment. Moreover, it is capable to collect regolith consisting of loose soil and pebbles while transmitting a low force into the system.

The brush sampling tool technology has demonstrated to be robust enough to manage the envisaged worst scenarios and has a high level of redundancy that increases the success chance in various sampling scenarios.

Further development is being carried out by studying the behaviour and functionality of the brush sampling tool in zero gravity conditions in a parabolic flight test campaign. These flight tests are very important to understand the representative sampling conditions in a low gravity body by getting rid of the gravity effect.

The success of this activity is presented as a significant achievement in the ESA exploration objectives to demonstrate capabilities of sampling technologies, in order to put Europe in a good technological position regarding sampling return missions. It will also open the path for running and future ESA exploration activities covering sampling handling chains, sample vessels developments, robotic arms or ERC technologies.

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