The Drill and Sampling System for the ExoMars Rover

Piergiovanni Magnani*, Edoardo Re*, Samuel Senese*, Francesco Rizzi*

Alessandro Gily**, Pietro Baglioni***

*Selex Galileo, Space L.o.B, Italy
e-mail: piergiovanni.magnani@selexgalileo.com

**Thales Alenia Space, Torino, Italy
e-mail: alessandro.gily@thalesaleniaspace.com

***ESA/ESTEC, The Netherland
e-mail: pietro.baglioni@esa.int

Abstract

The ExoMars Rover mission, presently scheduled for launch in May 2018, foresees the collection, crushing and distribution to on board scientific instrumentation of subsurface samples collected at a depth of up to two meters.

The system in charge to perform the sample acquisition and distribution operations is the Drill and Sampling system. It is based on multi-rod technology which allows to reach the desired drilling depth by assembling a string composed of one front end drill tool plus three extension rods. The development of the drill, presently in progress, has passed through the manufacturing and tests of many representative elements up to the assembly and test of a complete breadboard model. A very extensive test campaign has been performed including more than ten drillings at the full two meters depth. The results so far achieved clearly show the feasibility of 'deep drilling' in Mars like soil conditions and in a realistic drill-rover assembled configuration.

1 Introduction

The ExoMars Drill and Sampling system is composed of three main elements: the Drill Unit, the Positioner Unit and the Electronics Unit. The Drill Unit and Positioner Unit are installed on the front panel of the ExoMars Rover as schematized in Fig.1, showing the system in stowed configuration. The main part of the Electronic Unit is instead located internal to the Rover. Once on Mars the whole Rover is deployed on the Mars surface; the Drill Unit as well is deployed for the various operations by using the two degrees of freedom (d.o.f.) of the Positioner as shown in Fig.2 for the drilling scenario and Fig.3 for the sample discharge into the Sample Processing Facility.

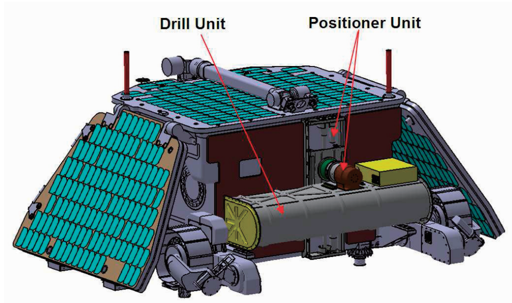

Figure 1 ExoMars Rover with the Drill and Sampling System shown in stowed configuration

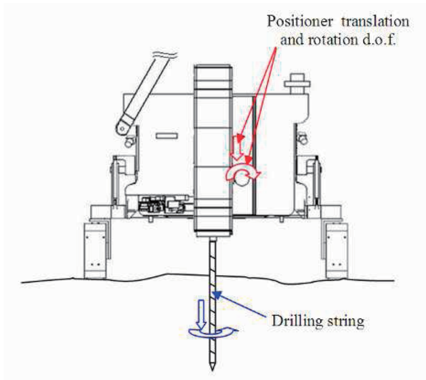

Figure 2 Drill and Sampling System deployed for drilling

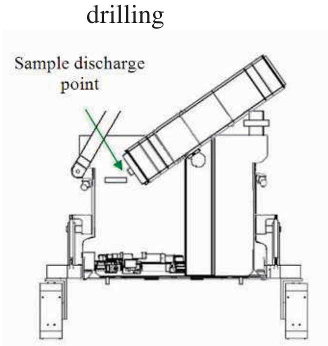

Figure 3 Drill and Sampling System deployed for sample discharge

2 The Drill and Sampling System

The requirement for ExoMars mission is to collect samples at a depth of up to 2 meters from the soil surface. To cope with such a challenging requirement a drill concept based on multiple rods has been devised where a total of four rods are assembled one after the other to obtain the full length drill string. The first rod is the real drill tool with sample collection capability; the other three rods are extension rods. The real drill tool is installed at the mandrel during launch, the other three rods are stored in a dedicated rod magazine together with a back up drill tool. All the rods are assembled together to collect a sample at 2 metres depth and then disassembled for recovery of the sample.

All the drill mechanisms and rods are contained in a light weight box (drill box) which is interfaced to the rover via a 2 degrees of freedom positioner (rotation plus translation joints). The positioner allows to lift the drill box from the horizontal stowage location, to put it in vertical position for drilling and then in a suitable inclined position for discharging the collected sample into the sample container. Normally the sample container lies within the rover body and it is extracted from it just for the short time necessary to accept the sample from the drill tool. During operations the thrust and torque exerted by the Drill are monitored and controlled in real time. The schematics of the drill and positioner architecture is shown in Fig. 4, with the list of the degrees of freedom. The main assemblies are: Drill sliding carriage, Drill translation group, Rod magazine group, Drill Tool, Extension rods, Drill positioner.

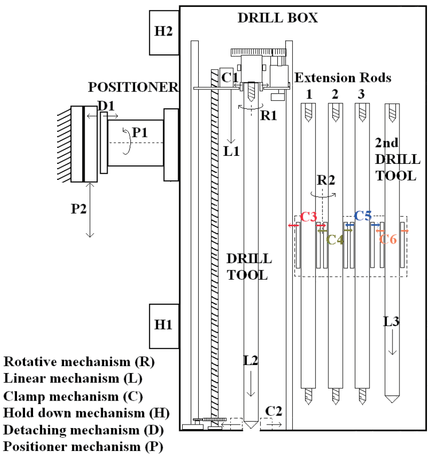

Figure 4 Drill and Sampling System schematics

In Fig.5 are shown some basic elements of the developed H/W: the integrated overall system, a portion of drill string, the forward part of the drill tool in drill mode and core mode.

Figure 5 Developed Drill and Sampling System H/W

On top of the basic function of sample collection, a down hole science capability is implemented by incorporating the spectrometer MA_Miss (MArs Multispectral Imager for Subsurface Studies) into the drill tool. The spectrometer is capable to perform soil stratigraphy in both visible and infrared spectrum; the connection schematic of Ma_Miss to the overall system is shown in Fig. 6. The spectrometer images (both visible and infrared) are conveyed to the surface via an optical link system composed of optical fibers interfaced with fixed and rotational optical joints; the illumination lamp is provided locally down stream via a dedicated lamp.

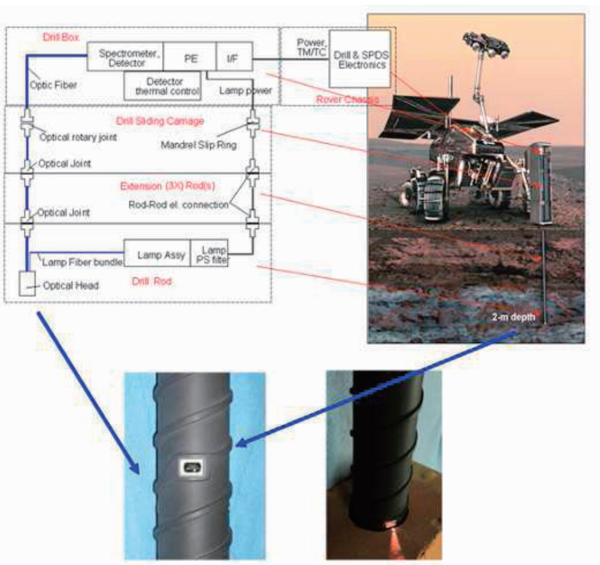

Figure 6 Schematics for Ma-Miss implementation

3 Main Tests performed

An extensive test campaign has been already performed on the developed H/W (BB of complete Drill and Sampling system, EM of Drill Tool inclusive of MA-Miss optics, specific BB parts). This performed testing include: *drilling and sampling in the 0.5m range in laboratory, drilling and sampling in the 0.5 m range in Mars like pressure and temperature conditions, sample discharge into the SPDS receiving port, complete drilling and sampling down to 2 m in laboratory conditions both via dedicated test equipment as well as with the drill integrated on the Rover*. These testing will be hereafter summarized.

3.1 Drill and sampling down to 0.5 m in laboratory conditions

Several tens of drilling and sampling operations have been performed in these conditions with the objective to verify the level of forces and torques required and the reliability of the sample collection and recovery operations. All these testing have been performed at SelexGalileo premises and hereafter some of the collected samples are shown.

Sand	
	Sample mass: 3.6g Type of sample: powder Volume: 2.55 cm^3
Regolith	
	Sample mass: 3.4g Type of sample: powder Volume: 2.48cm3
Tuff	
	Sample mass: 2.6g Type of sample: solid core and powder Volume:2.57cm3
Red Brick	
	Sample mass: 4.7g Type of sample: solid core - 2 pieces Volume: 2.61cm3
Marble	
	Sample mass: 5.3g Type of sample: solidcore Volume: 1.93cm3

Figure 7 Some examples of collected samples

3.2 Drill and sampling down to 0.5 m in Mars like pressure and temperature

The main objective of the test was to demonstrate the drilling and sample collection capability in Mars like conditions for what concerns temperature and pressure profiles. The test was conducted by SelexGalileo personnel at the facility of CISAS-Padova where the drill box was integrated on a supporting structure which contained in its lower part the soil specimen with a height of approximately 0.5 m. The whole structure was installed in a dedicated T/V chamber as shown in Fig. 8.

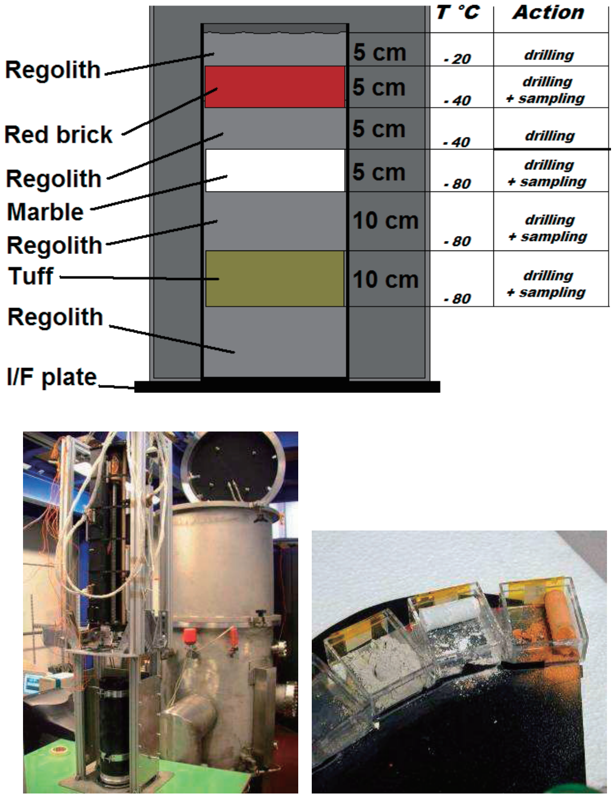

Figure 8 Set up configuration and collected samples during the test in Mars like environmental conditions

The sample temperature during drilling and sample collection/discharge was in the range of -80 °C +/-10 °C (or -40°C +/-10 °C depending on the test performed) with a pressure of about 10 mBar.

During the test the successful collection of three samples was achieved: the first sample taken into red brick at -40°C (mass 3.8 g), the second sample taken into marble at -80°C (mass 3.3 g), the third sample taken into regolith at -80°C (mass 5 g).

3.3 Sample discharge into the Sample Processing and Distribution System receiving port

Several sample discharge tests have been performed in representative geometric and H/W configuration. Each test consisted of a sample drilling and collection followed by a translation and rotation of the drill box (by means of the positioner d.o.f.) to align the drill tool with the SPDS container for the discharging action. The set up for this testing is shown in Fig.9

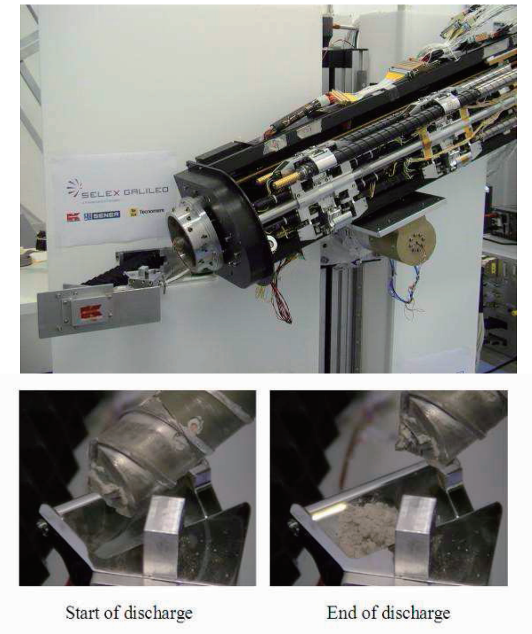

Figure 9 Set up configuration during the sample discharge tests and details of discharge

3.4 Complete drill and sampling down to 2 meters

The laboratory 'two meters testing' has been performed in two different operative conditions: with the drill system installed on a dedicated test equipment and with the drill system integrated onto the Rover Breadboard. In the first case the two meter sample has been prepared 'above the laboratory floor' in the second case the two meter sample has been prepared 'below the laboratory floor'. Prior to perform the integrated testing, hereafter summarized, the rod magazine (with its own clamping system) and the lower clamp were duly tested at Tecnomare premises.

Test with a dedicated mechanical set up 'above laboratory floor'

A dedicated set up was prepared at SelexGalileo to allow 2 m depth testing. This includes a sample container that is duly filled with materials in order to realize the desired stratigraphic characteristics.

The drill system was in this case installed at the top of the structure and a total of five tests have been conducted each taking approximately one/two days.

In Fig. 10 is shown the structural set up utilized while in Fig.11 is shown the implemented stratigraphy and an example of marble sample collected at two meters depth and recovered to surface. The maximum depth was achieved by using the drill tool and the three extension rods connected together to form a long drill string. The connection between the drill tool and the extension rod was done automatically during the execution of the test.

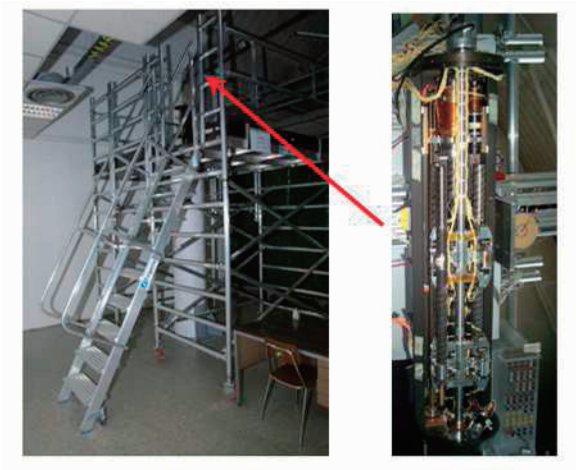

Figure 10 Structural set up for two meters test in laboratory conditions (drill on top)

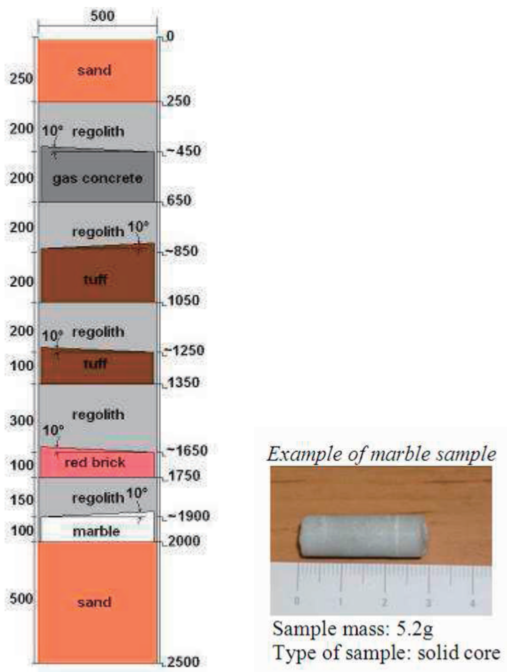

Figure 11 Stratigraphy implemented in the two meters test in lab and an example of collected sample

Test with the drill system integrated on the Rover Breadboard and sample specimen 'below the laboratory floor'

This testing has been performed with the Drill System (inclusive of positioner) integrated onto the Rover vehicle Breadboard and the two meters sample specimen prepared below the floor. The test campaign was conducted at ThalesAlenia premises in Torino by a joined SelexGalileo and ThalesAlenia team. In Fig. 12 is reported the utilized stratigraphy.

The fully integrated system was monitored during the test by a 3D optical measurement system capable to provide the position of the assembly key points (wheel' hubs, rover structure and drill box) in a very accurate way and at a frequency in the range of 50 Hz.

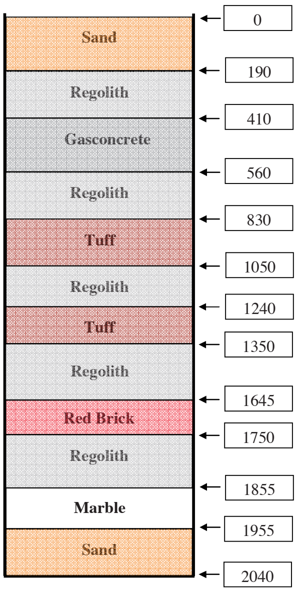

Figure 12 Stratigraphy implemented in the Drill-Rover integrated test

Furthermore the forces and torques transmitted by the Drill system to the Rover structure were also monitored by a 3F/3T sensor located at the Rover/Drill interface. In Fig. 13 is shown an example of one optical target located near a wheel hub and the 3F/3T sensor.

Figure 13 One of the optical targets located near a wheel hub and the 3F/3T sensor

Three system configurations were tested: Rover on pads-pads on sand (see Fig. 14), rover on wheels-wheels on hard material (see Fig.15), rover on wheels-wheels on sand (see Fig.16).

Figure 14 Rover on pads-pads on sand

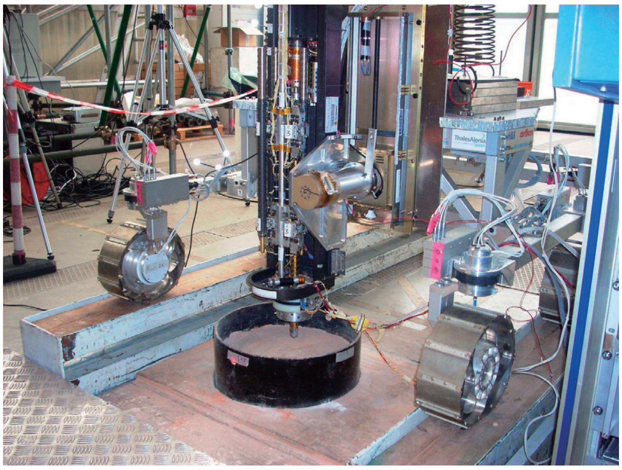

Figure 15 Rover on wheels-wheels on hard material

A total of five complete drill tests down to two meters have been successfully performed.

In Fig. 17 are shown a typical heap formation during drilling and a sample collected during one such test.

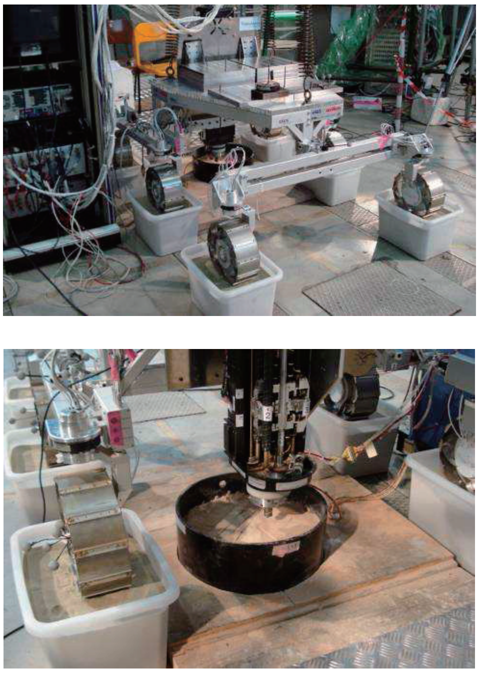

Figure 16 Rover on wheels-wheels on sand (rear view top, front view bottom)

Figure 17 Typical heap formation and a sample collected during integrated testing

3.5 Main outcomes from the tests so far performed and next scheduled testing

A number of different materials have been so far tested with characteristics ranging from weak non cohesive to very hard ones (see some examples in Tab.1) and in quite different operative conditions.

The results so far obtained support the feasibility of the drilling mission with limited use of resources in terms of the needed vertical thrust (Weigh on Bit), torque, power. An overall range for these parameters is summarized in Tab.2; clearly they strongly depend on the type of material being drilled.

The development is now continuing and the next tests foreseen include: quantitative assessment of life and tests in simulated Mars conditions with presence of important water/humidity content (6-7 mBar CO_2, temperature range -130/-80 °C up to -40/-20 °C along the sample column). Also the Mars soil stimulant will be prepared to be more representative of the types expected on Mars, in the first two meters depth, also according to the outcomes of the ESA Mars Soil Working Group.

These next testing are scheduled in the frame of the current year.

Also Ma_Miss spectrometer, implemented in the Drill tool EM (see also Fig. 6) will undergo extensive performance testing.

Material	*Density (g/cm³)*	*Compressive strength*
Sand	1.41	
Regolith	1.37	
Gas concrete	0.46	1-2 MPa
Tuff	1.01	Soft matrix plus very hard inclusion
Red brick	1.80	20-30 MPa
Marble	2.75	100-110 MPa

Table 1 Some of the materials used for characterization

Parameter	Range	Remark
Vertcal Thrust	10 – 450 N	Upper value for hard materials and widely used bit
Advancing Speed	0.3 – > 20 mm/min	Lowest values for marble like material
Torque	1 – 6 Nm	Upper value for hard material and widely used bit
Power	70 - 80W	In the worst contition

Table 2 Summary of Drill key performances

4 Acknowledgment

A special acknowledgment is given to our colleagues of Tenomare and Sener for their very important contribution in the design and manufacturing of important parts of the drill system.

A special thank is also given to Prof. Debei of CISAS, for his contribution to the testing activity in Mars like conditions, and to Thales Alenia integration team, in particular to Paolo Lippi, for the excellent collaboration during integrated test campaign.

5 Conclusions

In this paper the main capabilities of the ExoMars Drill and Sampling System have been summarized.

The design, breadboarding and testing activity so far performed provide a positive confirmation on the feasibility of automatic drilling and sample collection down to 2 metres in Mars scenario in a variety of conditions. The resources in terms of mass and power needs, as well as the characteristics of the collected samples, are in line with expectations.

Further verification are now planned relevant to the issues of life quantification and drilling capability in presence of important fractions of water/ice.

The gained information certainly will allow to enter phase C/D with a mature design an high degree of confidence.