LUNAR ICY SOIL SAMPLING

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ABSTRACT

After the confirmation of water ice presence in permanently shaded regions near to the Poles of the Moon (L-CROSS mission), the interest in future mission landing to Earth’s satellite has grown stronger.
One major objective in going back to the Moon is to investigate the presence of such resources that will become very important in scenarios of future exploration and for the establishment of a more sustainable human presence on the Moon. Those ices can be found at very high latitudes, where the lunar regolith could resemble an admixture of ‘highland type’ soil with entrapped volatiles/ices in different forms with temperature as low as 25 K. For this reasons, drill machinery, sampling tools and operational strategies need to take into account very stringent requirements regarding reduction and control of physical contamination and preservation of ice content.
Specifically looking at in-situ analysis scenarios, it is very important to limit the amount of heat transfered into the soil and to the acquired sample up to and including the point where the sample is delivered to the scientific instruments. To reach this goal, classic rotary drilling may not be the correct strategy due to relative inefficiency of the drilling process and associated heating of the sample; instead, a drilling machine capable of penetrating the soil with the aid of a hammering actuator could guarantee the desired efficiency and advancing velocity.
In the frame of ESA’s Lunar exploration activities, Selex ES is leading the study and development of a specific drilling system and sampling tool which can address the above mentioned requirements. This paper will cover the thematics related to the development of such systems, starting from the recreation of a representative icy simulant (and methodologies tested), the design and testing of drill concepts (that can operate with and without hammering action) and the associated sampling tool mechanism.

1. DRILLING AND SAMPLING REQUIREMENTS

Next missions may be targeted at very high/low latitudes and expected regolith can be characterized by the presence of ‘important’ fractions of vola-tile/ices among which water ice.

‘Ice entrappment’ Water ice acts as a bonding mechanism between regolith particles and it certainly may have an important effect on the strength of the regolith. Experiments performed studying general permafrost mechanics shows that the Unconfined Compressive Strength varies depending on the amount of water ice (UCS increases with ice content up to full saturation) and on temperature, reaching a maximum value at -80°C. A possible behaviour of soil strength w.r.t. ice content percentage and tem-perature are reported in Figure 1. Specific cutting resistance behaves similar to UCS, drillability itself may be diagnostic of water ice content in situ. Strength (UCS) as high as 95 MPa can be encoun-tered in saturated conditions (~ 11.9 %) is present.

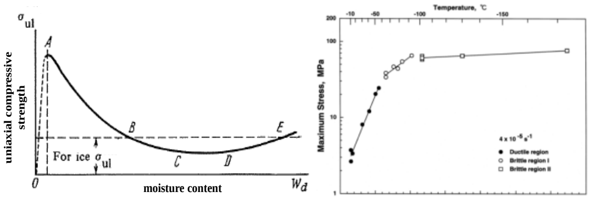

Figure 1 . Soil strength trend with respect to ice concentration (left-Tsytovich, 1973, Fig. 80) and soil temperature (right-courtesy Kris Zacny)

The main soil requirements given for the Drill System development are summarized in Figure 2. Concerning specifically the samples, the key re-quirements are summarized as:

- *sampling depth: selectable down to 2 meters;*
- *sample size: ≈ d= 10 mm, L= 30 mm.*

Parameter	Unit	Value (referred @ 2 m depth)
Bulk density	*g/cm³*	*2 (2.24 with 11.9% wt of water ice)*
Temperature	*K*	*120*
Thermal conductivity	*W/(cm*K)*	*$2.5*10^{-2}$*
Water content	*%*	*11.9 (saturation)*
UCS	*MPa*	*95*

Figure 2 - Main soil requirements given for the development of the Drill System

For effective sampling and sample handling operations at such conditions important issues need be taken into account as far as sample(s) integrity:

- integrity of physical form (e.g. association of vola-tiles with soil components, avoiding phase transi-tions, stratigraphy/layering);
- quantitative integrity (e.g. minimize volatiles loss);
- chemical contamination (i.e. introduction of for-eign material into sample; sample-to-sample cross contamination);
- isotopic integrity (i.e. avoiding altering isotopic compositions of samples).

Drill machinery, sampling tools and sampling strategy will be key points in order to achieve such stringent conditions/requirements.

2. DRILL PRELIMINARY CONFIGURATION

The Drill System is now conceived as formed by two main elements (plus control electronics): the Drill Box and thePositioner. These main units and a installation sketch on the Lander are shown in Figure 3. The positioner is now conceived as a single degree of freedom while the Drill proper (see also Figure 4) it is based on a single string driven by a roto-hammer mandrel plus a translation stage and capable to reach selectable depth ranging from surface down to 2 meters.

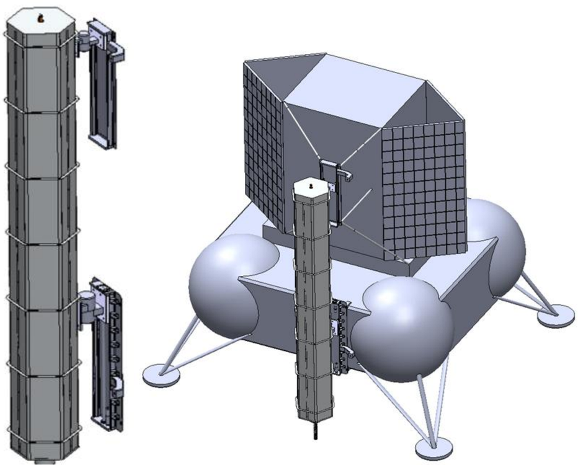

Figure 3 - Pictorial view of Drill and positioner (left) and schematics of installation aside the Lander (right)

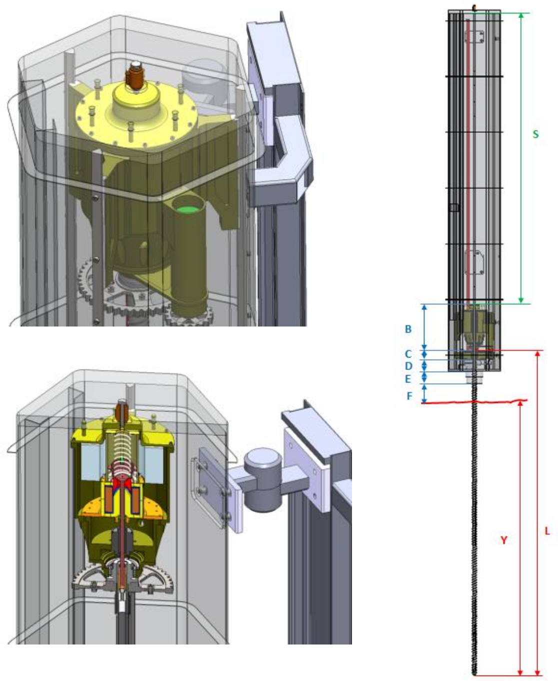

Figure 4 - Internal of Drill box (left) and drill string extended (right)

The sampling tool (in charge of the final sam-pling action) is located in the front part of the drill string (see Figure 5) and is designed to perform a core-like sampling. It is equipped by sample retain-ing spikes, temperature sensors and its collecting volume can be partly selected and is locally motor-ized.

Figure 5 - Some details on sampling tool

3. CURRENT TEST ACTIVITIES ON PROTOTYPE CUTTING HEADS

In the frame of the running activity, two typology of tests are foreseen:

- early tests on prototypes of cutting/sampling heads;
- tests at Drill Breadboard level.

Concerning the tests on prototypes of cut-ting/sampling heads they are being performed on on six different solution/sizes, some of them based on PCD diamond technology and some on carbide technology. Concerning the soil simulant (representative of near South Pole conditions), an admixture of:

- ‘base regolith’ of NU-LHT-2M type (similar to the one of highland);
- volatile/ices entrapped in different forms (with percentages of 6% and 11.9% saturated);

is considered also in agreement with a Scientific Workshop on the ‘preparation of Lunar Polar Soil Simulants’ held in ESTEC in 2013. Inclusion of pebbles will be evaluated for the final testing. The tests are performed in rotary mode with a partial support of weak hammering acton. The soil specimen temperature during test is in the -165/-100 °C range and in kept under glove box together with the drill tool. In Figure 6 are shown the prototypes tools being tested. In Figure 7 is given some details of the set up for the drill tools prototypes testing and some of the samples collected are shown.

Figure 6 - Picture of prototype drill tools being tested

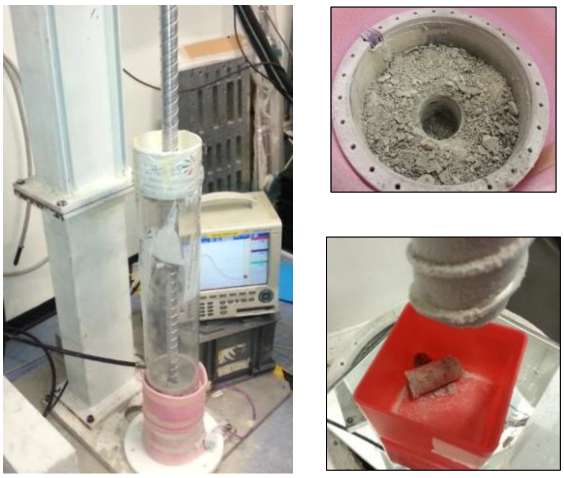

Figure 7 - Some detail of test set up for prototype drill tools testing and some of the samples collected

A Drill Breadboard is designed and will be manu-factured representative of the final Drill System model as far as the key aspects of: roto-hammer group, length of drill string, sampling tool and asso-ciated masses. *This Drill BB will be tested* over strokes of 700 mm utilizing a specific test equipment both in laboratory conditions (with the sample specimen conditioned in the -165/-100 °C range under glove box and afterward in a dedicated Thermal Vacuum (T/V) chamber with the soil specimen conditioned at -180 °C. In Figure 8 is shown is shown the sketch the Drill Breadboard in its lab set up, the schematics of installation in the large T/V chamber and the picture of the T/V chamber utilized.

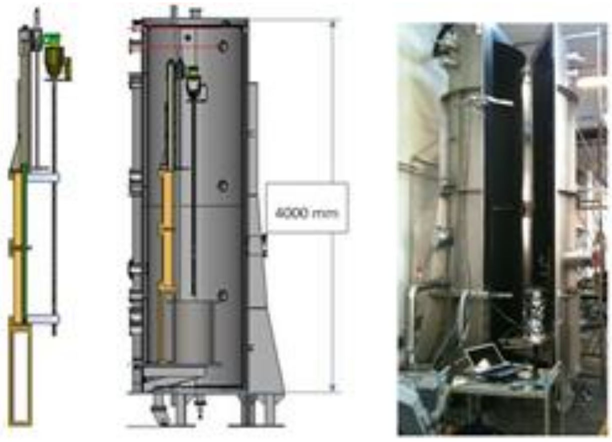

Figure 8 - Schematics of Drill BB, its installation in the large T/V chamber and the picture of the T/V chamber

4. CONCLUSIONS

Three specific activities are being presently developed for Moon low latitude scenario at Selex-ES on behalf of ESTEC. The outcomes will encompass Drill System and Sampling Tools Bread-boards specifically tested in Moon South Pole icy regolith and deatailed Icy Sample Handling chain analysis with special attention to sample integrity and preservation.