Comet Sample Acquisition for ROSETTA Lander Mission

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Abstract

ROSETTA/Lander is being developed with a combined effort of European countries, coordinated by German institutes. The commitment for such a challenging probe will provide a unique opportunity for in-situ analysis of a comet nucleus. The payload for coring, sampling and investigations of comet materials is called SD2 (Sampling Drilling and Distribution). The paper presents the drill/sampler tool and the sample transfer trough modeling, design and testing phases. Expected drilling parameters are then compared with experimental data; limited torque consumption and axial thrust on the tool constraint the operation and determine the success of tests. Qualification campaign involved the structural part and related vibration test, the auger/bit parts and drilling test, and the coring mechanism with related sampling test. Mechanical check of specimen volume is also reported, with emphasis on the measurement procedure and on the mechanical unit.

The drill tool and all parts of the transfer chain were tested in the hypothetical comet environment, characterized by frozen material at extreme low temperature and high vacuum (–160° C, 10^{-3} Pa).

1 Introduction

ROSETTA is a cornerstone mission of ESA 2000 Scientific Program that is expected to reach P/46 Wirthanen comet in the year 2011 and perform nucleus analysis, after nine years of cruise in the solar system and two significant flybys with asteroids. Among the space missions for discovery of small bodies, this is one of the most challenging.

While the main body of the spacecraft will remain in orbit and will contribute with high resolution imaging, a probe will descend and anchor to the comet surface. The probe, called RoLand (Rosetta Lander), will carry within its scientific package the automatic laboratory SD2, for acquisition of samples and experimental data collection on the nature of this particular celestial body.

A special anchoring and landing gears device will allow to grab on the hypothetical ice-rock mixture, as reported in the simulated scenario of Figure 1 (MPAe web page, Germany).

Once anchored, the Drill Tool will be able to drill multiple samples on the landing site, because of the rotational degree of freedom of Lander on its supporting gears. Comet terrain samples will be cored at different depths up to 230 millimeters below the surface, and discharged into mini containers for in-situ analysis. This will be a unique opportunity for the scientific community to study the hypothetical primordial ice-rock mixture at different depths.

The Tool is designed to bore the surface, to acquire samples, and to distribute specimens to scientific instruments; the mechanical unit and its mechanisms have been conceived for correct operation after a long cruise phase, and to withstand the expected cryogenic environment.

An automatic robust procedure for acquisition of samples and size measurement is under testing, in order to define a nominal behavior for a wide range of material properties. A priori knowledge of the expected situation will reduce the amount of tele-commands; the highest degree of autonomy is desirable, for the large time delay between earth and comet.

Lander balcony is equipped with the SD2 scientific package. This Italian payload consists of a control electronics and an electro-mechanical unit. The latter is composed of: 1) a tool for samples coring at different depths; 2) a set of containers for samples storage; 3) a volume checker; 4) gas analyser, microscope and spectrometer as instrumentation. Once anchored, the Lander will be able to rotate allowing SD2 to drill multiple samples on the landing site down to 230mm (see Figure 2), and to fill up the 26 containers with a multiple set of specimens.

Besides high communication time delay, the autonomous laboratory will have to face a vast range of materials and harsh environment (foreseen temperature up to –160 °C). Moreover, handling of samples in low gravity environment, minimal contamination and cross-contamination of samples are within the main requirements.

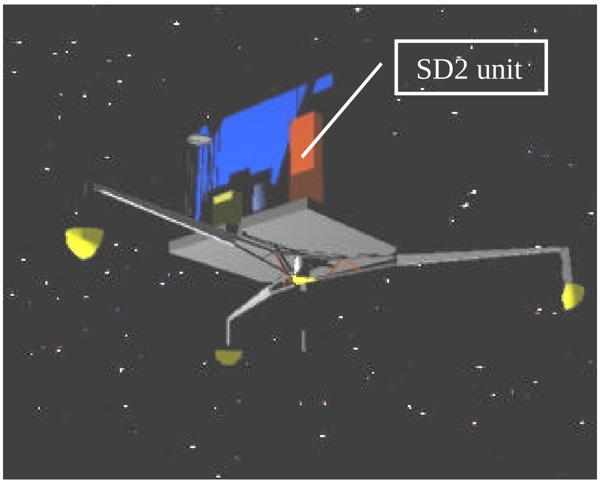

Figure 1: Landing of RoLand probe: balcony with scientific instruments (Courtesy of MPAe).

This work, led by Italian Space Agency, is the last step of studies performed in comet drilling and sampling by European teams [1, 2, 3], under ESA contracts during the last decade. Tecnospazio (Prime Contractor), Tecnomare, Media Lario and Dallara compose the SD2 industrial team.

There is also a JPL-NASA and ESA effort related; a number of compact drilling and sample systems [4, 5, 9] are under advanced development and early testing phase within Mars Exploration Program and Planetary exobiology in general [10]. Extension of the concept of autonomous laboratories for future missions and in-situ analysis is under development [6] by Italian scientific community.

2 Modeling and design

A computer simulation of both cuttings flow dynamics and forces acting on the tool was done, in order to aid the drill tool design and to predict drilling parameters.

Rotational speed and feed motion (control parameters) must be adequate for materials ranging from soft snow to gas-concrete, and must guarantee effective drilling operations with limited axial force. This parameter depends strictly on the anchoring nominal value; it was experimentally set at 10N, after a campaign of anchoring test and grabbing test of the Lander on the comet surface.

Drilling conditions **n** and **U** (respectively rotational speed and translation speed at drill bit) were calculated for achievement of positive cuttings flow, to avoid jamming of the auger, minimum power usage due to mission constraints, and axial force.

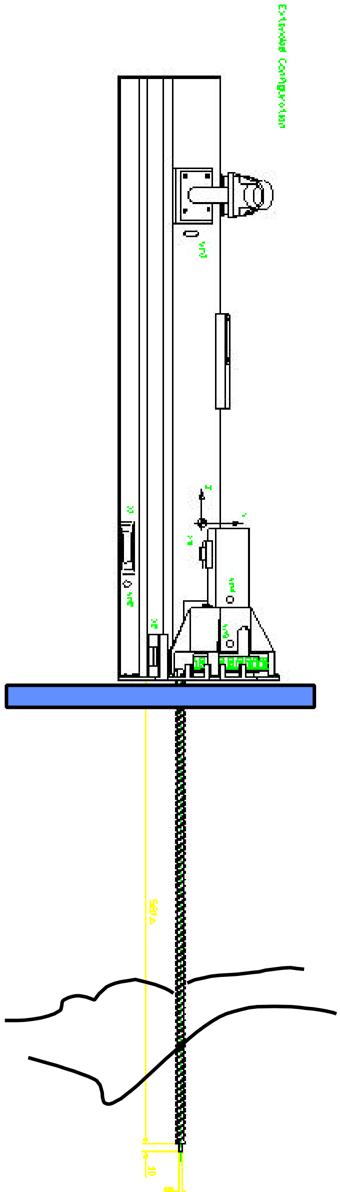

Figure 2: SD2 operational concept (courtesy of Tecnospazio).

Figure 3 reports the parameters that govern drilling behavior of the tool. Selection of auger design parameters *h, t, a*, were imposed by the mechanics of cuttings [6]; main external dimensions D_i and D_o were constrained by the inner mechanisms.

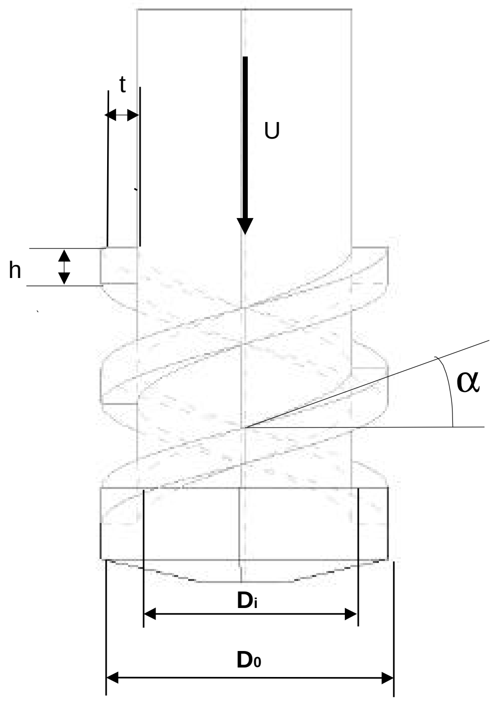

Figure 3: main design parameters

Calculated drilling parameters **n** and **U** were experimentally confirmed by test on expected comet-like materials. Drilling campaign (see Drilling Test results) underlined tool capability in boring materials with compressive strength up to 3-5Mpa. Proper setting of translation speed **U** (< 1-2 mm/s) provide a working range for rotational speed around 100rpm; these control parameters pair allow to achieve positive cuttings flow and to maintain designed axial force.

Knowing the value of E_S (strictly related to the compressive strength of materials [7]) it is possible to calculate the torque required, given the diameter and the drilling conditions:

$$T = \frac{D^2 U E_s}{8n} \qquad [\text{Nm}] \qquad (1),$$

where D is the average external diameter. The power associated with this process is:

$$P = 2\,pnT = pD^2 U E_s / 4 \qquad [\text{w}] \qquad (2)$$

and does not depend on the rotational speed of the drill.

A huge data base of experimental drilling data is under processing, in order to tailoring the theoretical model to the comet like material drilling.

3 Launch verification and structural issues

The lengthened structure of the drill/sampler Tool, with a free span of 600mm between the pinned joints, constrained the structural design. Hybrid stainless steel and titanium alloy structure is the solution adopted for the EQM model. For manufacturing and AIV reasons the tubular structure was split into two parts; connections of the parts was realized in Titanium to reduce the non-structural masses and to avoid cold welding of the screwed joints.

Numerical and experimental modal analysis provided a natural frequency close to 90Hz. A non-linear effects due to the pin-hinged constraint was experimentally determined; natural frequency increase versus input acceleration magnitude. This non-linear stiffness increasing allowed to pass the qualification test, even with the 10g input level in the 25-80Hz range.

Figure 4 reports the FEM analysis of the vibration test equipment model, used for test campaign of D/S Tool models.

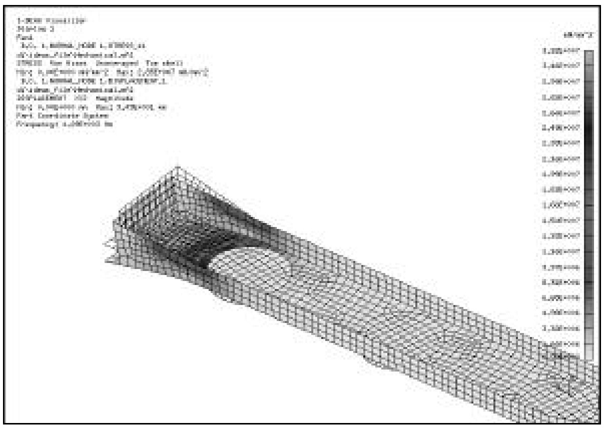

Figure 4: FEM analysis on the vibration equipment for D/S Tool.

Stress analysis and mechanisms functionality after simulated launch phase were tested. After positive tests on Phase B model and EQM models, flight and spare models followed the same dynamical behavior.

Design of inner mechanisms was principally driven by the avoidance of clearance modification, due to thermal effects, and avoidance of cold welding. The first requirement was solved with enlarged tolerances and EQM testing, while the letter by means of facing different materials where a non negligible pressure arise during operation.

Stiff structure, efficient drilling features and weight within the specified requirement (less than 350 grams) were achieved already in early EQM prototype.

4 Drilling tests

Remote control delay during the real mission, suggests to reduce the adjustment of the controlled parameters, and to select them a priori.

Very low influence of rotational speed on torque consumption was experimented; this is in accordance with (2). Vertical thrust was less than 10N with feed motion in the range of 1-2 mm/min. This result was stated testing the materials at low temperature.

In Table 1 are reported the general results of the operation. Several materials were tested; the worst case is the presence of hard inclusions. Values of 15-20Mpa for compressive strength (solid ice or rocks), forced to slow down the feed motion to 0.2 mm/min and will cause the time of perforation to last for hours.

Figure 5 reports the Pahse B test equipment for low temperature testing (without vacuum facility).

Axial Force	< 10 N
Cutting Torque	< 0.05 Nm
Rotational speed	100-150 rpm
Feed motion speed	< 1-2 mm/min
Compressive Strength	< 2.5÷3.5 N/mm^2

Table 1: drilling parameters in thermal-vacuum conditions

Figure5: low temperature drilling

Some experimental data on Gasbeton material are reported in Figure 7. Low temperature testing, represented with stars, bolted dot, and dark squared icons, allow to extrapolate a relation between the axial force and the translation speed **U**. Relation is almost linear, and drilling operation with speed lower than 2mm/min achieve the desired axial thrust.

Experimental data at on-ground temperature (lighter square and triangle icons) allow proof of the linear behavior versus speed increasing; it is also possible to measure the relation of the specific energy E_S with temperature.

5 Sampling tests

Sampling tests consists in two phases: the sample coring and the sample discharge into the mini-containers. The experiments performed were monitored by means of video cameras. Amount of sample material was slightly different versus material type, but enough for science experiments to be performed.

5.1 Sample coring

In order to prevent mix of soil from different depths, the corer will be active when no drilling action will be done. Coring

The amount of material (about 20-30mm^3) for instruments is risen up on the SD2 main unit level (say the balcon level, on-board the Lander).

5.2 Sample discharge

Discharge of the samples is totally autonomous and was successfully tested in T/V conditions. The mechanism is passive and actuated by the feed motion degree of freedom of the drill tool. A vacuum proofed camera and a load cell were monitoring the operation during the qualification test; a nominal procedure and some safety procedures were obtained. Only tested procedures will be implemented during the acceptance of flight model.

6 Volume checking of samples

A check on the cuttings volume put into the container is necessary, and performed with the Volume Checker device. The subsystem is designed for measurement of soil height into the container. The mechanical unit conceptual design is reported in Figure 6; the second motor is used both for measurement (exploiting the back-EFM) and for redundancy in emergency case. The exploitation of the same electromechanical element both as actuator and sensor is an advantage for the procurement and qualification activities; also fault tolerance improvement is achieved.

In Figure 9 is reported the experimental set-up for T/V testing of volume checker mechanical unit; the video camera for monitoring is also present. Experimental results provided a repeatability and accuracy within the specification (5% of the working stroke) imposed by the open loop operation, during 500 cycles test.

Conclusion

Early EQMs prototypes have already been tested. Tests at low temperature (liquid nitrogen) and high vacuum provide a look-up table of control parameters that limit the force exerted by the tool, during comet like material drilling. Tests of the final Flight Model are in progress, providing proof of the expected performances. Stability of the Lander is experimentally proved, with comparison between anchoring (provided by other technological team) and drilling experimental data. Sampling and discharge have been tested with success; experimental filling the specimen container with cuttings was achieved, at quantity large enough for in-situ science. The processing demonstrates visibility and access for microscope analysis and experiments. Volume checking of the material released into the container gave the required accuracy of measurement, and allow to state the feasibility of analysis.

Integrated tests with complete SD2 will have the capability of automatic multiple discharge operation (up to 26 mini containers).

Acknowledgments

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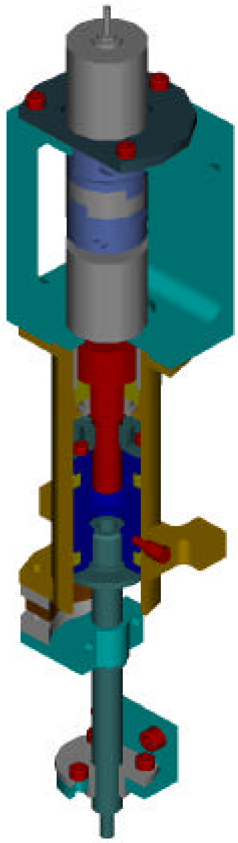

Figure 6: Volume Checker mechanical unit

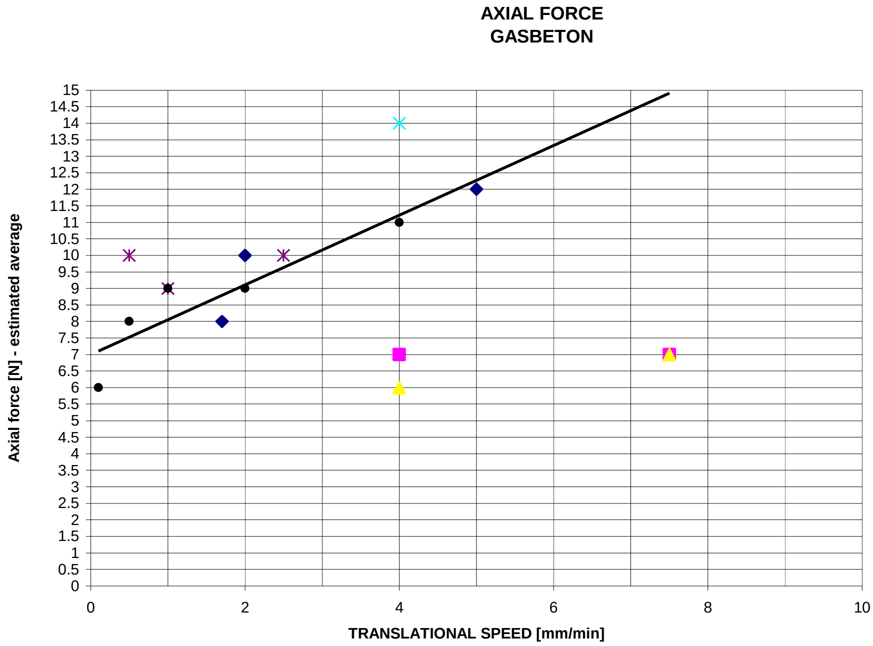

Figure 7: axial force for a representative comet-like material versus translation speed; trendline is obtained from low temperature data (stars, circle and squared icons), while extra trend data are at on-ground temperature.

Figure 8: discharge operation into a dummy container

Figure 9: Volume Checker test equipment