ROSETTA PHILAE SD2 DRILL SYSTEM AND ITS OPERATION ON 67P/CHURYUMOV-GERASIMENKO

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ABSTRACT

Rosetta Lander Philae approached and landed on the surface of comet 67P/Churyumov-Gerasimenko on the 12th of November 2014.
Among the specific Subsystems and instruments carried on board, the Drill, Sample and Distribution System (SD2) which was in charge to drill the surface of the comet, take comet's soil sample(s) and distribute the collected sample to different instruments.
Rosetta has been launched in 2004 and, after very complex orbital trajectories and specific commissioning events, met and carried out a rendezvous with the comet; after ten years cruise and three subsequent touch down, Philae eventually landed on the comet surface. On the 14th of November 2014 SD2 was decided to be operated on the comet.
This paper provides an overview of the achievements during the operational phase on the comet and will summarize the basic characteristics and peculiarities of SD2 drill system.

1. SD2 MAIN CHARACTERISICS

SD2 Drill System, which Principal Investigator is Prof. Amalia Ercoli Finzi (Politecnico di Milano), has been developed by Selex ES SpA (formerly Tecnospazio SpA) with the subcontractor support by Tecnomare S.P.A. (controlled by ENI), Dallara Automobili and Media Lario. SD2 has been developed under a contract awarded by the Italian Space Agency (ASI).

The main requirements and features taken as reference for the design are summarized as follow:

- *Sampling depth: 250 mm*
- *Sample size: 20-30 mm3 (more than 4 samples to be collected);*
- *Operative temperature range: -160°C to +40 °C;*
- *No warm up power available for mechanics;*
- *Capability to Drill 2 MPa class soil without exceeding 10-15 N vertical thrust;*
- *Cruise time: > 10 years*
- *Platform: S/C (lander) anchored and stabilized*

The SD2 design has resulted as a four degrees of freedom (d.o.f.) robotic system and is assembled as three major components (see also Fig. 1):

- Mechanical Unit;
- Electronic Unit;
- Harness (electrically connecting Mechanical Unit, Electronic Units and Philae).

The picture of SD2 is shown in figure 2.1.

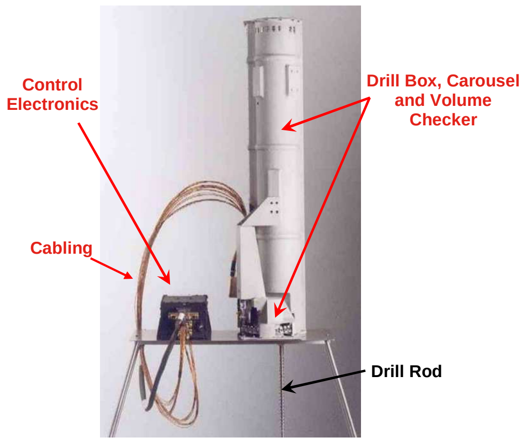

Fig. 1 SD2 Flight Model

The *Mechanical Unit* (with a total mass of about 4 kg) comprises the Drill proper based on single stroke technology (and inclusive of roto-translation group, sliding carriage, drill rod with sampling tool, and structural elements), the Carousel and the Volume Checker. A total of four actuations are present (inclusive of motors, gears and sensors).
Concerning the Carousel it installs a total of 20 ovens for sample acceptance and distribution to on-board scientific instrumentation. Two typology of ovens are present:

- *Medium Temperature Ovens (MTO capable to be heated up to 200 °C) equipped with sapphire observation prism to serve CIVA instruments;*
- *Hogh Temperature Ovens (HTO capable to be heated up to 600 °C) to sereve Gas Evolved Analyser instrumentation (COSAC, PTOLEMY).*

Both MTO and HTO are equipped with four contacts for heater and temperature sensor interface.

The *Electronic Unit* (of mass about 1 kg) comprises the following main functions:

- *Digital Processing Unit*
- *Motor drivers and sensor management*
- *Embedded control SW*

In Fig. 2 and 3 are shown some details of the Drill, Carousel and drill rod.

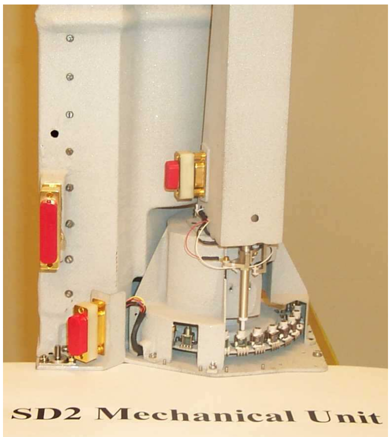

Fig. 2 Some details of the Carousel and Driil Box

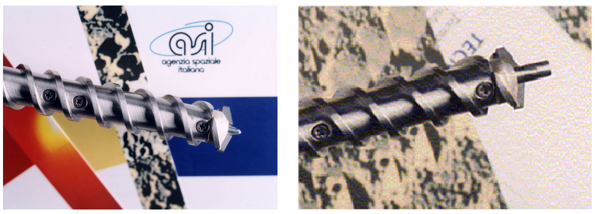

Fig. 3 Some details of the Drill Rod with Sampling Tube retracted (drill mode-left) and extracted (sampling mode-right)

In Fig. 4 are shown some details of the Carousel during integration: the two types of Ovens are installed and the two Tapping Stations are placed and properly aligned. In Fig. 5 are shown some details the ovens with the optical prism (in MTO) and the four contacts (both MTO and HTO). The Tapping Stations as well as the HTO have been developed by Max Plank Institute and integrated in SD2 by Selex ES.

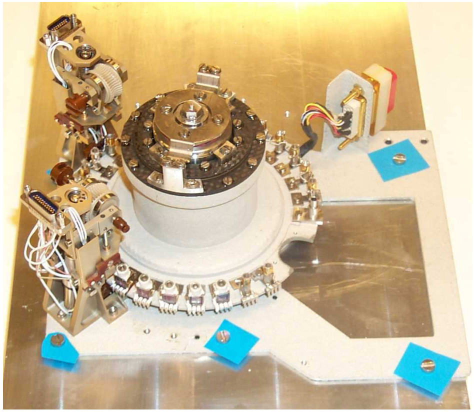

Fig. 4 Carousel during integration with installed the Ovens and the Tapping Stations (developed by MPAE)

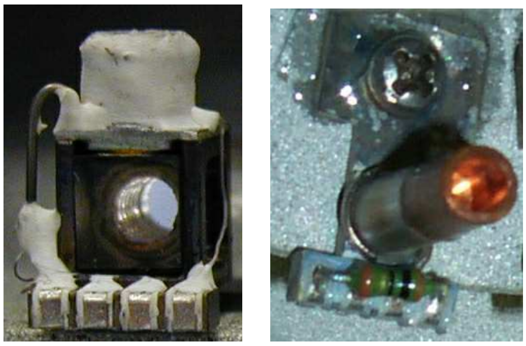

Fig. 5 Some details on MTO (left) and HTO (right)

2. SOME TEST RESULTS DURING DEVELOPMENT

As previously pointed out SD2 has been designed to be operated from an anchored platform with thrust and torque reaction capability.
A thorough test campaign had been performed during development and qualification in order to verify the attainment of the requirement and get confidence in the on the reliability of operations.
As an example in Fig. 6 is shown a typical profile measured in a drilling and coring operations with some of the key phases highlighted.
To be noted are the drill phase, the pre-core verifications, the load relied prior sampler activation, the load injected by the sampling tube release and the coring action.
Also shown in an oven filled with material.

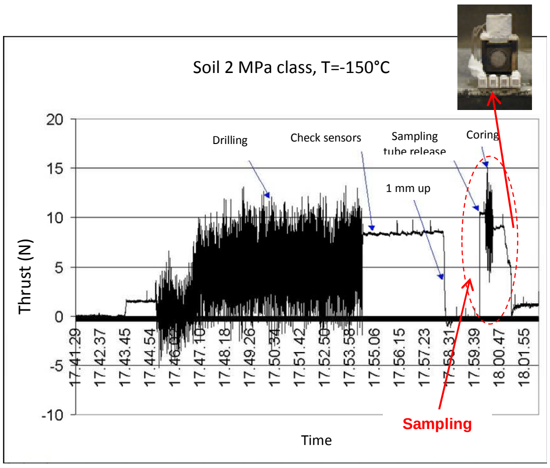

Fig. 6 An example of data profile recorded during test

During operations (all temperature conditions conditions) the power consumption was limited resulting on a ceiling of about 16-18 W during drilling operations.

3. MISSION PHASES

3.1. Commissioning's Phases

Regular SD2 health checks were performed during the cruise phase. Right after launch, the instrument was put through a rigorous commissioning process of its electronic box, which involved

- software boot;
- check of the EEPROM status;
- verification of all communications protocols with CDMS;
- check of the Carousel interfaces with CIVA, COSAC and PTOLEMY.

After commissioning, a total of 13 passive and active payload checkouts (PCs) were executed until the deep space hibernation phase. Besides carrying out regular health checks, SD2 had the opportunity to activate and operate its mechanisms, as well as refreshing its EEPROM. The list of SD2 activities executed during the PCs is reported in Tab. 1. Only the translation and rotation resolvers have been activated during the passive payload checkouts. This allowed the team to check the instrument status, and to measure the drill and carousel positions and compare them with the expected values. Active payload checkouts were devoted instead to operate the drill and the carousel. More specifically:

- downward (DW) and upward (UW) drill translations were executed to check the status of the drill translation motor;
- clockwise (CW) and counterclockwise (CCW) drill rotations were executed to check the drill rotation motor status;
- carousel movements were performed for stand-alone and combined tests with CIVA, COSAC, and PTOLEMY;
- the EEPROM memory was refreshed before hibernation.

The telemetry produced during the operations shows that SD2 behaved nominally during all PCs. The collected data was consistent with the performed activities, and the telemetry of both carousel and drill movements matched expectations within the admissible tolerances.

Table 1 SD2 activities during payload checkouts

PC#	**Type**	**Activities**
0-3, 5, 9, 13	passive	Standard checkout
7, 11	-	Cancelled
4	active	7 carousel rotations for combined tests with COSAC and CIVA
6	active	• 7 carousel rotations for combined tests with COSAC and CIVA • 1 CW and 1 CCW drill rotation
8	active	• 6 carousel rotations for combined tests with CIVA • 1 CW and 1 CCW drill rotation • 1 DW (to 0.3 mm) and 1 UW (to 0 mm) drill translation • EEPROM refresh
10	active	• 8 carousel rotations for combined tests with COSAC and CIVA • 1 CW and 1 CCW drill rotation • 1 DW (to 2.5 mm) and 1 UW (to 0 mm) drill translation
12	active	• 2 carousel rotations for combined tests with COSAC • EEPROM refresh

3.2. On Comet Phase

On the 12th of November 2014 Rosetta Lander (Philae) landed on the surface of comet 67P/Churyumov-Gerasimenko. Not all went as planned: some elements of Philae landing system (the cold gas thruster, the anchors and the helices) were unable fix onto the surface at touch down: two re-bounces occurred and finally the Lander remained on the surface at the third touch-down. As far as SD2 operations, with respect to the nominal conditions, above events caused three major consequences:

- the lander was not anchored onto the surface (no reaction available for the thrust the Drill would have generated);
- the Lander (drill base) possible movements during drilling operations might have favoured jamming conditions;
- limited allowed power (power generation capability of the body mounted solar cells was seriously limited due to the un-lucky Lander final position).

Despite the non-nominal conditions, Rosetta and Philae's project managers decided to eventually let SD2 operate on the comet on the 14th of November 2014. SD2 was commanded to reach the position 560 mm (corresponding to a distance of 468.5 mm from the lander baseplate), perform the sampling sequence, discharge the sample into a high-temperature oven, and serve the sample to COSAC for later analysis. More specifically, the operation sequence included the following activities:

1. Drill bit rearming (the sampling tube had indeed been travelling in extracted configuration during the entire cruise phase);
2. Drill roto-translation to position 560 mm;
3. Sample acquisition: the sampling tube was extracted and the drill rotated for 20 seconds to perform a coring of the soil;
4. Drill translation back to position 0 mm to uplift the drill rod (and sampling chamber);
5. Rotation of the carousel to put HTO #17 under the sampling tube;
6. Sample release inside HTO #17;
7. Rotation of the carousel to put HTO #17 under COSAC main port.

In addition, the Carousel was eventually rotated back to its home position to allow PTOLEMY perform a sniffing activity.

The telemetry produced shows that SD2 performed nominally. All mechanical operations and kinematical trajectories were executed correctly: the commanded drill and Carousel positions were reached within the admissible tolerances and the movements were performed with the commanded speeds. In addition, SD2 power and energy consumption matched the expectations.

Figure 7 shows the drill position profile during the roto-translation to 560 mm and the subsequent translation back to 0 mm. As can be seen, the drill bit reaches the required position of 560 mm. The different slopes and durations of the two movements are due to the different commanded speeds: a speed of about 7 mm/min was commanded for the roto-translation to 560 mm, whereas a speed of about 13 mm/min was used for the translation back to 0 mm.

Figure 8 illustrates the Carousel position profile during the last Carousel movement. The rotation started from position 15120 arcmin, which corresponds to having HTO #17 under COSAC main port. After about 80 s, the Carousel reached the commanded home position (i.e. 0 arcmin, or equivalently, 21600 arcmin) with an error of 1 arcmin.

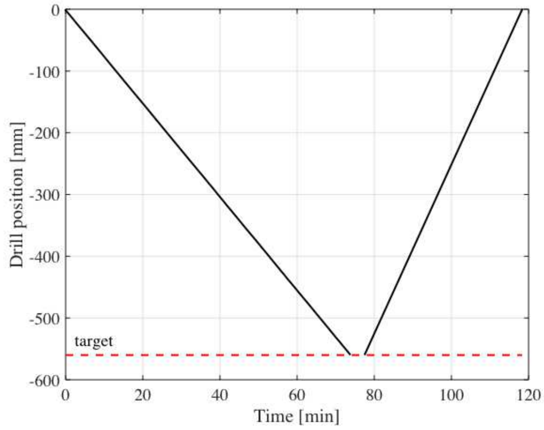

Figure 7 Drill position profiles during the roto-translation to 560 mm and the translation back to 0 mm

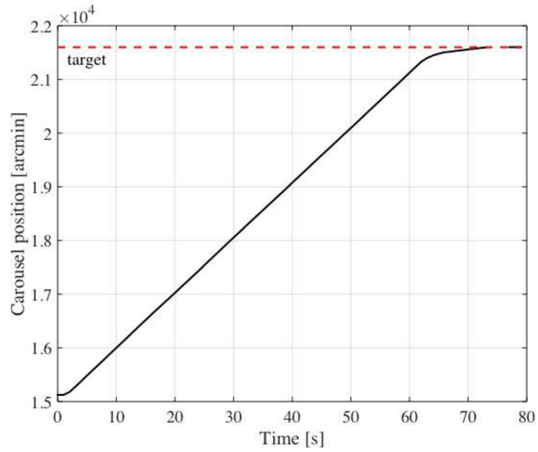

Figure 8 Carousel position profile during the Carousel rotation back to home position (rotation shown 108°).

The nominal behavior of SD2 during on-comet operations is a remarkable success: after more than ten years in space and a dramatic landing, the system has proven to satisfy the design requirements and to withstand the stringent operating conditions. Nevertheless, the telemetry of SD2 is not sufficient to rigorously confirm that the drill bit has reached the soil, and that the sample has actually been collected in the sampling tube and discharged into the oven. In fact, due to the non-nominal landing and the unknown Philae conditions on the comet, the soil itself could also be too far away to be reached by the drill.

Other instruments on board Philae may help to clarify this point. The camera system ROLIS could be used to reconstruct a three-dimensional model of the comet surface under the lander. The SD2 team is currently interacting with ROLIS team to determine the distance of the soil from the lander baseplate in the drilling area, so as to check that it is compatible with the commanded roto-translation of 560 mm.

4. CONCLUSIONS

With an adequate design and technological solutions SD2 System has been able to achieve the target performances and to operate correctly in its functions both during commissioning and during on comet operations ten years after launch.

To achieve this special design has been applied to the key parts including cutting technique and drill-sampling design, composite materials, doped dry lubrication, brushless actuators, medium temperature ovens design, rad-hard electronics).

On the Comet the actuated parts all performed correctly and within the utilized expected consumptions. Due to the three Philae touch-down occurrences an unwanted operational scenario arose (platform not anchored, limited power available, unclear soil-balcony relative position) with a balcony-soil distance potentially exceeding the expected range.

The experience gained in Rosetta SD2 development and operations is being utilized in Exomars Drill now in qualification and in the next generation roto-hammer drill being now being studied for the Moon South pole scenario.

5. REFERENCES

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