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Deep drill (DeeDri) for Mars application

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Abstract

Deep drilling on Mars can provide soil samples taken from depth which are of great scientific interest for analysis by the instrumentation present on-board a mission vehicle. The key to a successful sample collection and delivery is the development of a performing and reliable drill tool with sample collection capabilities, properly integrated in a complete drilling system.

Within this context, Galileo Avionica is involved in the design and development of drilling systems, including hardware prototyping and testing, suitable to operate in planetary and cometary environments. Several prototypes of drilling tools have been designed, manufactured and tested and new concepts are in the development pipeline. The testing so far performed indicate the feasibility of drill tools suitable to operate in very different types of soil and capable to reliably collect, recover and distribute samples to the possible scientific instrumentation. The preliminary design of integrated drill systems, both employing a single drill tool or multiple rod assembled during operation, shows their ability to achieve performances in line with the resources allowed by a Mars vehicle.

This paper summarises the major developments being performed in this respect by Galileo Avionica with particular reference to the on going DeeDri (Deep Drill) program under ASI contract [1].

Keywords: Drill; Sample; Penetration depth; Single-rod; Multi-rod

1. Introduction

The DeeDri program is funded by the Italian Space Agency (ASI) in the frame of the cooperation with NASA for the Mars Exploration Missions: within this program a core sampler mechanism is foreseen to collect Mars surface and subsurface soil samples and release them to the scientific instruments or storage system on the planetary landing vehicle. A prototype of the core sampler mechanism has been developed by Tecnospazio and Galileo Avionica in order to verify the functionalities, identify criticalities and better define requirements for future developments (Re et al., 2002).

The drilling tool prototype consists of a hollow steel tube equipped with an auger thread on outer surface and a drill tip at the lower end. The tool drills a hole 35 mm in diameter and its central part (piston) can be withdrawn so to form a volume to allow sample core to be collected inside this opening. The core sample collected is 14 mm in diameter and 25 mm in length. The mechanism allows to collect not only core samples but also powder-like samples. The tool diameter can be scaled down to allow drilling and sampling functionalities with a lower demand of power and force/torque actions.

The flight version of DeeDri is aimed at a larger penetration depth than the prototype and can be designed either as a single- or multi-rod system. The multi-rod approach is a specifically developed assembly technique of an appropriate number of drill rods: indeed the rods can be pipelined (and subsequently disassembled) with a specific drill tool forehead. The achievable drilling depth of the DeeDri drill is up to 3 m. The drill can support direct down hole science by installing inside specific dedicated scientific instrumentation.

2. Drill system configurations

Two different DeeDri system conceptual designs are presented in this paper:

1) Single-rod design suitable for 1 m depth.
2) Multi-rod design suitable for 3 m depth.

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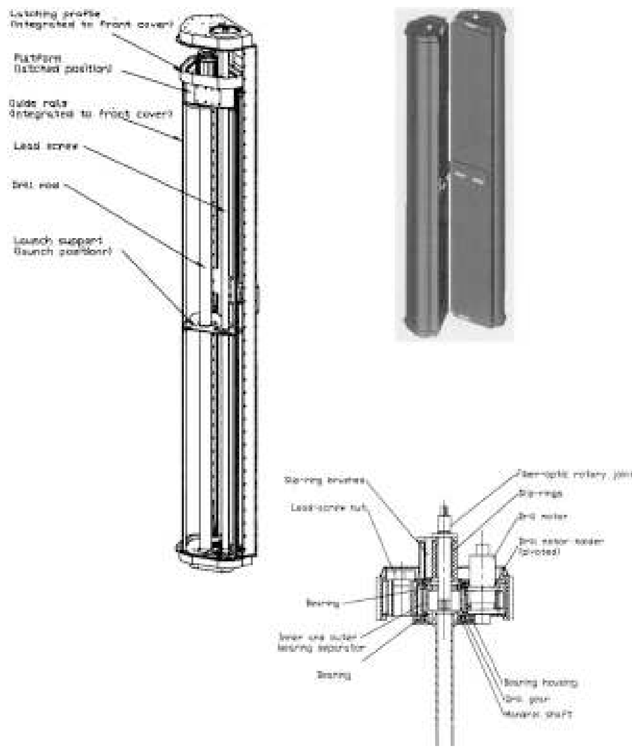

Fig. 1. The single-rod drill (1 m depth).

Both concepts make use of a special drill and sampling tool developed on purpose for the Mars drill; a prototype of this tool has been manufactured and tested with different materials as explained later.

Multi-rod design makes use of a specifically developed drill pipe coupling concept based on thread, like the couplings of most of the conventional fully automatic rock drilling machines. Among several different connecting schemes the thread turned out to be most reliable with least risk for unintended release of the rod or failure to couple. The threaded coupling cannot be accidentally opened (in which case the complete drill string might be lost) by pulling, pushing or clock-wise twisting, or by any combination of these. Furthermore, autonomous release of the coupling during counter-clockwise rotation presents a naturally built-in safety mechanism that allows release of the drill rod in case it should get stuck in the soil. The coupling is equipped with an electrical feed-through for 10 lines to facilitate active drill-tool operations and other down-hole instrumentation.

Both concepts include a slip ring assembly (10–15 lines depending on concepts) and a flex-cable assembly to transfer power and data between s/c and possible drill tool instrumentation. In addition the system provides means to measure drill thrust, drilling torque and drill depth, and also to support the moving parts during s/c launch. Components selected for concepts design are either readily available as space-qualified (connectors, motors and resolvers) or off-the-shelf commercial high-quality products (slip ring assembly, force sensors, bearings) which can be considered applicable for space application with specific adjustments.

2.1. Single-rod design

This design aims at high reliability and low mass by using one single drill tool (Fig. 1) without any disposable or interchangeable components.

The single-rod design, drilling a hole 25 mm in diameter up to 1 m in depth, has dimensions 1251 mm $\times$ 220 mm $\times$ 155 mm, and it weighs about 7.32 kg, including an active motor operated sample collection tool inside the drill rod, and external cabling, positioning mechanism and control electronics.

The collected sample can be ejected for separate sample storage or sample processing system on platform. After this, the sampling procedure can be repeated, thus allowing multiple sampling in several desired locations or varying depths. In addition to electrical feed-through, the system includes also an optical rotary feed-through (2 lines) for optical data transfer between drill tool and spacecraft.

Complete redundancy of the system may be achieved by duplicating complete drill assembly.

2.2. Multi-rod design

The multi-rod design aims at a greater penetration depth with reduced system height in order to fit inside a more restricted volume on a small-sized planetary exploration vehicle. The drill rod is divided into up to ten separate drill pipes that are stored on a carousel inside the drilling system (Fig. 2).

The system provides a good versatility, since some of the drill pipes may be replaced with additional drill tools having different designs for different sampling operations. The introduction of a carousel and drill string extending/retrieval-system adds, however, further functionalities, increasing the overall complexity.

The multi-rod design presented in this paper aims at drilling into a depth of 2.5 m, with a drill string consisting of ten drill pipes 23 mm in diameter. The current design is sized 540 mm $\times$ 175 mm $\times$ 175 mm weighing about 8300 g (excluding external cabling and control electronics). Penetration depth of 3 m can be achieved by making the system 5 cm higher (with some mass increase). On the contrary, for a reduced 1 m drilling depth (always based on a multi-rod design) the height of the system can be lowered to 390 mm which decreases the system mass of about 400 g.

Components selected for the design are commercial high-quality products available off-the-shelf. Preliminary motor and gearbox selection is based on the choice of "well sizing" to guarantee sufficient performance margin. Further analyses in detailed design phase may reveal that smaller

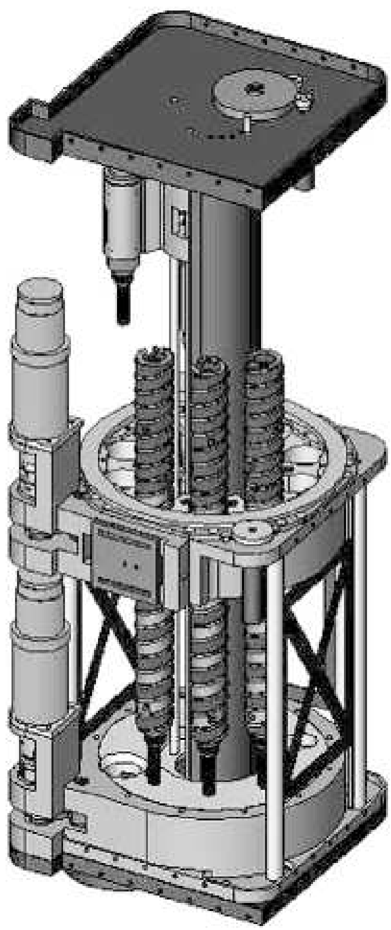

Fig. 2. Multi-rod drill (2.5–3 m depth).

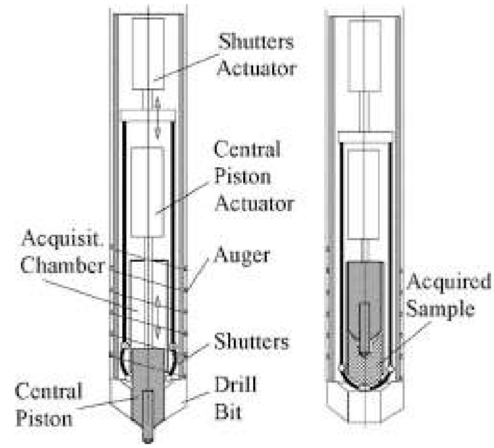

Fig. 3. Drill tool schematics (no scientific instrumentation is shown).

motors may suffice and the total envelope and mass may be reduced.

3. Drill tool prototype and test results

To support detailed design activity, as well as to get confidence on the actual achievable performances, a complete drill tool prototype has been manufactured.

The baseline tool schematics is shown in Fig. 3.

It includes:

- Main tube with external auger, provided with cutting bits.
- Central piston, rotating together with the external auger; it can be uplifted upon command so to create a volume available for sample housing; it is also provided with cutting bits.
- Shutters (or single shutter), which can be activated upon command and have (has) the purpose to both detach the root of the sample from the soil and contain the sample (either solid or powder). The shutter(s) can be activated only when the central piston is uplifted and a sample (e.g. core) is contained in the dedicated volume.
- Actuator(s), to move the central piston and the shutters.

To describe the sequence of operations of the drill tool, reference is made to Fig. 4.

- The sequence starts as showed in sketch 1, with the drill tool in a normal drilling configuration, i.e. the central piston is in drill position and the shutters are (necessarily) open.
- In order to start a sample acquisition, the drill tool is arranged as in sketch 2: the central piston is uplifted and the shutters are still open.
- The drilling action is then continued to perform actual coring till the filling of the sample volume, as shown in sketch 3.
- The shutters are then commanded to close, while the drill tool still rotates, so that a core sample is detached from the soil and fully encapsulated in its container, as shown in sketch 4.
- The drill tool leaves the bore hole and brings the collected sample, as in sketch 5.
- Finally, the sample is discharged into the container, sketch 6.

The system can collect samples starting just below the surface up to the maximum depth that depends on the drill tool length. The collected samples can either be directly discharged into the ports of scientific instruments for in situ analysis or, if required, stored in dedicated sample containers, for example mounted on carousels (not included in DeeDri single-rod and multi-rod designs presented in previous section).

The prototype tool (Fig. 5) drills a hole 35 mm in diameter and 250 mm depth. The core sample collected is 14 mm in diameter and 25 mm in length. It has been decided to start with a drill rod of such a diameter (which would allow the inclusion of down hole complex scientific instrumentation) in order to get proper confidence on the maximum requirements in terms of vertical thrust, torque, power. The tool diameter can be scaled down to smaller dimensions, thus

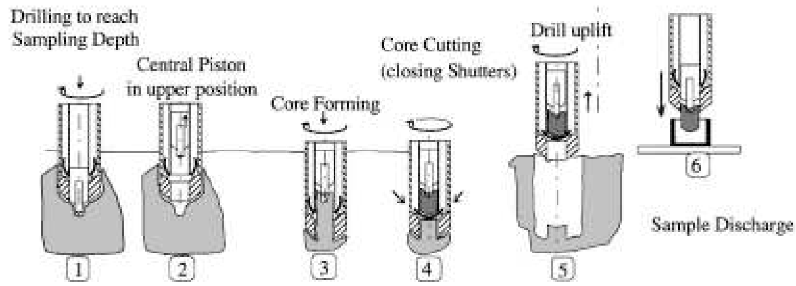

Fig. 4. Sample collection and discharge sequence.

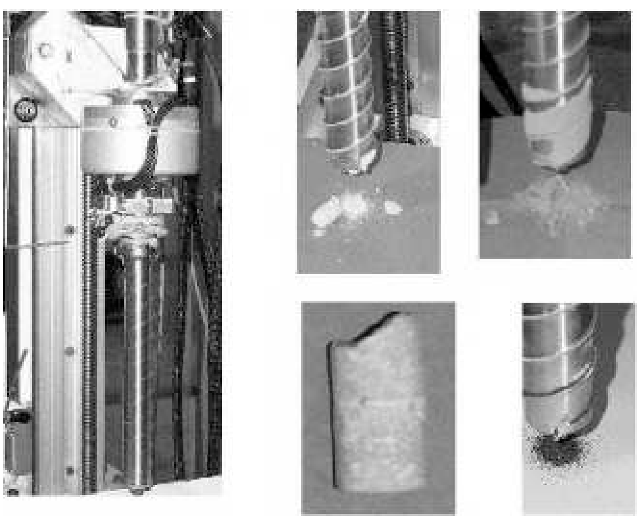

Fig. 5. The tool prototype and some collected samples.

allowing drilling and sampling functionalities with a lower demand of power and force/torque actions, at the expense of the room potentially available for accommodating instrumentation.

The drilling and sample collecting tests were carried with several materials:

- *Gas concrete*: density 0.46 g/cm^3, compressive strength 1–2 MPa.
- *Tuff*: density 1.01 g/cm^3, compressive strength 1 MPa for the matrix and 10–50 MPa for the inclusions.
- *Travertine*: density 2.44 g/cm^3, compressive strength 40–60 MPa.
- *Sand*: density 1.43 g/cm^3, grain size 0–0.3 mm.

The test have been performed by utilising a specifically developed sensorised test equipment capable to measure and to keep under control all the basic parameters associated to the drilling operation (drill rotation speed, drill penetration speed, drilling thrust, electric power consumption). The drill rotation actuation is equipped with an electrical slip ring which allows to feed electrical and electronic devices located inside the drill rod like the actuator for sample grasping and potential instrumentation devoted to down-hole science.

Table 1
Tool prototype test results

Property	Sand	Gas concrete	Tuff	Travertine
Thrust (N)	3	15	6	200
Drill torque (Nm)	0.6	0.9	0.4	2.5
Drill RPM	22	130	150	70
Feed rate (mm/min)	10.0	4.0	1.4	1.3
Drill intake power (W)	7.5	14.5	7.5	29.0

Table 1 presents the test results and describes performance of this sampling tool prototype. It can be seen that thrust, drill torque and drill intake power tend to increase by increasing the compressive strength of the material under test. It is shown that intake power of less than of 30 W suffice to drill material comparable to rocks of medium hardness. Marble and basalts would require higher power suggesting an appropriate scale down of the tool diameter to keep power and thrust within the resources possibly available on future landing systems.

4. Conclusion

The design prototyping and testing activities so far performed pointed out the system capability of obtaining good performances, compatible with the constraints of a landing mission on Mars. A full verification of a possible drill system for Mars requires further extensive design, prototyping and testing in order to cover all involved issues like reliability of multi-rod mounting/dismounting operation, wear of drill tool under prolonged drilling operations, behaviour of long tools in heterogeneous subsurfaces.

Tecnospazio is presently performing an activity on behalf of ASI aiming at an extensive design and verification of the drilling system leading to a complete and successful feasibility demonstration.

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