CRUX AND ICEBREAKER ROTARY-PERCUSSIVE LUNAR DRILLS.

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Introduction: There are many reasons for penetrating below the surface of an extraterrestrial body. One of these reasons include obtaining core or powder samples that have been preserved and unaltered for millions of years for scientific analysis or for resource investigations to enable In Situ Resource Utilization. Another reason is to provide subsurface access for in-situ scientific instruments such as heat flow probes and neutron spectrometers (to identify water-ice deposits). There are also a number of challenges associated with penetrating extraterrestrial bodies. These include specific mission requirements (depth, size of a sample, acceptable level of contamination), mission constraints (mass, power, volume, communication delay) and environmental constraints (temperature, atmospheric pressure or vacuum, dust, geological uncertainty). Having such a large number of variables leads to diverse drilling approaches.

Minimizing push force on the drill, or so called Weight on Bit (WOB), in low gravity environments such as on the Moon is of paramount importance. This is especially true if the mass of the drill platform (rover or a lander) is also very low [1]. For this reason, we designed and built two Rotary-Percussive drills (CRUX and IceBreaker), since WOB required to penetrate hard formations when using percussion is much lower than when using pure rotary action. The CRUX drill is not vacuum rated while the Icebreaker drill is and thus can be tested in a vacuum chamber.

CRUX Rotary-Percussive Drill: The CRUX drill is a rotary percussive drill designed as a highly capable testbed platform (Figure 1). The actuators for rotation, percussion and preload are large enough to allow testing to large depths with minimal concern of the drill getting stuck and having to be manually pulled out. This capability allows for quantifying various drill faults such as auger choking. The drill has been used to determine power, energy (power x time), and Weight on Bit (WOB) required to drill in various formations such as ice, limestone, basalt, and frozen Arctic Devon Island breccia. The drill includes the following capabilities:

- Rotary Percussive Drill head with two separate actuators enabling the following drilling modes:
    - Rotary
    - Percussive
    - Rotary Percussive
- Auger drive capabilities of 2 kW
- Percussive drive capabilities of 200 W
- Weight on Bit (WOB) capability of 1100 N
- Depth Range > 1 m with a single drill string
- Electrical feed throughs for down hole sensors such as a thermocouple
- A dedicated Torque and Temperature sensors for measuring torque and temperature of the bit only. This data decouples torque due to cuttings removal from the torque due to rock breaking and supports drill automation.
- Window in drill string for down-hole camera

Figure 1. CRUX Rotary-Percussive drill inside a vacuum chamber. The chamber allows testing to >1m depth in vacuum and low temperature conditions.

IceBreaker Vacuum Rated Rotary-Percussive Drill: In order to test the rotary-percussive drill in a vacuum environment, we build a novel rotary-percussive vacuum rated drill (Figure 2). The drill is capably of drilling through ice, icy-soils and hard rocks. The drill has a power of 400Watt and can decoule percussion from rotation. This allows investigation of different indexing (blows per revolution) in at attempt to optimize the system.

The drill has a four channel slipring and drill strings with electrical feedthroughs. The drill strings also have robotic connectors; this allows robotic making and breaking of drill strings and in turn automated drilling to depths in excess of the drills' stroke of 1m.

This drill (Figure 3) will be lab and vacuum tested in July of 2010 and it will also be field tested in the Antarctic Dry Valleys in Novermber/December 2010.

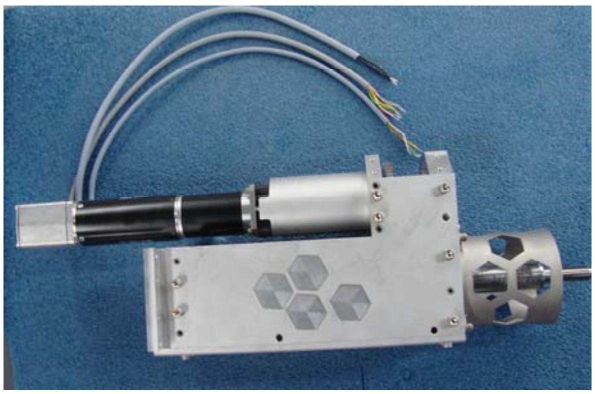

Figure 2. IceBreaker Vacuum Rated Rotary-Percussive drill.

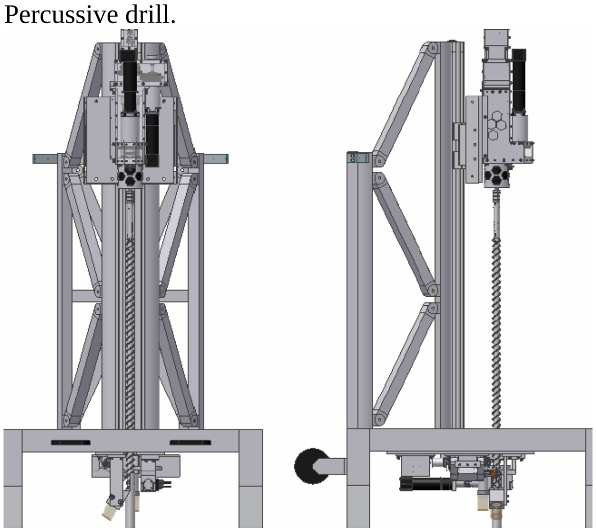

Figure 3. IceBreaker Rotary Percussive Drill System.

Vacuum Chamber: In order to bring the sampling technologies into the required Technology Readiness Level (TRL) of 6, the hardware has to be extensively tested under relevant environmental conditions. These conditions are always much different than the conditions we find on Earth, and the exact conditions depend on where (what extraterrestial body) the system will be deployed. For example, if the target planet is Venus, the hardware has to be tested at ~90 bar pressure, CO_2 atmosphere, and 460 °C temperature. For Mars, the conditions are more benign: low pressure of 1-11 torr and temperature of the order of -80°C to +25°C., whilefor the Moon, the conditions are more extreme (hard vacuum and temperature ranging from as low as -240°K to as high as 123°C).

Simulating accurate environmental conditions not only is required for demonstrating the hardware, but also to investigate how a sample is behaving during a sample acquisition.

In addition to atmospheric conditions (pressure, gas, temperature), it is also important to simulate the appropriate formation (soil, rock, ice). For example, drilling into icy-soils will be different than drilling into pure ice. Sample acquisition of icy-soils will also be different than sample acqusition of rocks.

In order to address environmental testing of drills, diggers, and penetrometers we developed a large environmental chamber system.

Vacuum Chamber Description: The Vacuum chamber consists of two smaller chambers assembled on top of each other in such a way that the inner walls are flush (Figure 1). The bottom chamber is 84 in tall by 38 in x 38 in, while the top chamber is 48 in by 38 in x 38 in. Having two chambers instead of one allows the two smaller chambers to be used independently of each other.

The chamber has 20 inch flanges on the top and the bottom. This allows inserting an additional cylindrical vacuum extension on top to accommodate a longer penetrometer stage. Putting a similar 20 in diameter cylindrical extension at the bottom, allows the vacuum chamber to extend below the floor (into a trench, for example). A rock or a soil sample could be placed in this lower cylindrical section.

The chamber reached 0.01 torr with two pumps. The cooling of sample is achieved via a closed loop cooling system.

References: [1] Bar Cohen, Y., and K. Zacny, Drilling in Extreme Environments: Penetration and Sampling on Earth and other Planets, Wiley-VCH (Sept 15, 2009).