LUNAR PROSPECTING DRILL. K. Zacny[1], G. Paulsen[1], P. Chu[1], J. Kleinhenz[2], J. Smith[3], J. Trautwein[3], J. Quinn[3], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com, [2]NASA Glenn Research Center, Cleveland, OH, [3]NASA Kennedy Space Center, FL

Introduction: Near term exploration of the Moon will most probably focus on northern or southern cold traps. This is because these regions were found to contain large fraction of water and other volatile resources within the top meter of the regolith [1]. Water and volatiles are not only of interest for science investigations but also as source of valuable resource.

For over a decade, Honeybee Robotics has been focusing on development of a one meter class robotic drill systems, called Icebreaker, for capturing of icy samples on Mars. Although majority of work has been done having Mars polar caps as primary target, the sampling approach and hardware is applicable to the lunar drilling goals, with some modifications to account for hard vacuum and more extreme temperatures (low and high) [2-4]. The Lunar Prospecting Drill (LPD) is a 'Moon' rated copy of the TRL 5/6 Mars Icebreaker3 (IB3) drill, the third generation of rotary-percussive one meter class drills. The 'Moon' rating included changes to actuator lubrication, upgrading some hardware subsystems to account for Coefficient of Thermal Expantion (CTE), and installing heaters on critical elements. In August of 2014, the LPD has been undergoing a series of tests in a Lunar chamber (VF13) at the NASA Glenn Research Center (GRC).

This abstract describes the drill and reports on preliminary test data from the lunar chamber tests.

Subsystems of the Drill: The drill system can be divided into five major components as described below and detailed in **Figure 1**.

The Deployment Z-stage is a pulley based system (more dust tolerant than a ballscrew) that lowers the Drilling System to the ground. It can preload the Drilling Z-Stage with up to 500 N if required; although the exact preload is software limited to whatever value is achievable given rover weight. The baseline preload is 150 N.

The Drilling Z-Stage is also a pulley based system that lowers the Sampling Auger up to 1 meter into the ground. It should be noted that the pulley system was selected not only because of its dust tolerance but also to enable efficient propagation of percussive energy generated in a Drill Head hammer. Since the Drill Head is free to move up and down on the carriage connected to the pulley via set of cables, vibrations are not transferred to the drill structure and the rover as much. The Drilling Z-Stage can also apply up to 500 N of downward force (called Weight on Bit or WOB) and it can retract the drill by applying up to 500 N pull force (note that in this case the force is reacted into the ground). During drilling operation, the WOB is software limited to approx. 100 N.

The Drill Head Assembly consists of 1. 200 Watt Rotary Actuator to spin auger up to 180 rpm; 2. 200 Watt Percussive Actuator to hammer the auger at 1600 blows per minute with 2.6 Joules per blow, and 3. 4 channel slipring to enable temperature measurements at the drill bit.

The Auger is made up of three parts: 1. Transport Auger is a top 100 cm section designed for moving cuttings out of the hole in the most efficient manner; 2. Sampling Auger is a bottom 10 cm section designed for capture and retention of sample within the flutes; 3. Drill Bit is responsible for penetrating through dry and volatile rich formations in most efficient manner enabled by custom tungsten carbide cutters. It has a temperature sensor for monitoring the subsurface temperature during drilling and measuring subsurface temperature when the drill is lowered onto the hole bottom.

The Sampling Assembly consists of an Auger Tube, passive rotating Brush, and a Spout. As the Sampling Auger passes through the Auger Tube, its flutes rotate the Brush (the Auger and the Brush form worm gear configuration), and the Brush in turn scrapes the sample on the flutes into the Spout. If the sample needs to be discarded, the Spout is positioned above the ground. If the sample needs to be captured, the Spout is positioned above the sample cup.

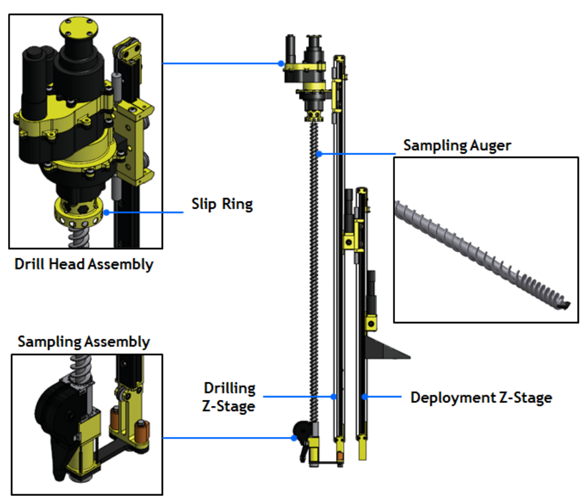

Figure 1. Lunar Prospecting Drill subsystems.

Sampling Process: The sampling routine follows 'Bite' sampling approach which is similar to peck drilling (**Figure 2**). The drill penetrates subsurface in 10 cm depth intervals and upon capture of a 10 cm sample, it retracts back to the surface. The sample is then either discarded or transferred to an instrument cup. A Near Infrared Spectrometer could view the cuttings as they fall onto the ground to determine if the sample is volatile rich and in turn decide whether to send a sample to a GCMS. To capture next sample, the drill is lowered back into the same hole and the process repeats. This approach has many advantages. The stratigraphy is somewhat preserved because a 1 meter hole is now represented by 10 samples. Lowering the drill into a hole each time allows measuring of subsurface temperature and in turn plotting of thermal gradient. When a sample is being analyzed, the drill is above the hole and in turn in a safe position. Moving the drill out of the hole also allows the drill and the subsurface to cool down.

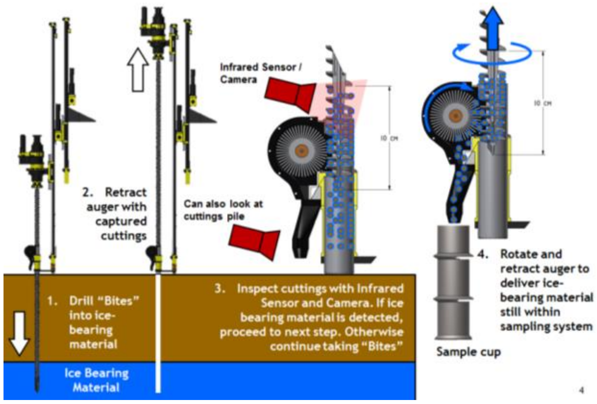

Figure 2. "Bite" Sampling approach.

Testing. A number of tests were performed inside a lunar vacuum chamber, VF13, at the NASA GRC to determine sampling efficiency as well as fraction of volatiles (water) loss during sample capture and delivery to an instrument (**Figure 3**).

The lunar chamber vacuum level was ~10^-4 torr while the LN2 shroud was kept at approx. -150 °C. The sample of NU-LHT-3M lunar regolith simulant was mixed with 5 wt% water and compacted to ~1.5 g/cc, and frozen prior to installing within VF13. During vacuum chamber tests, the sample bin was chilled to -130 °C. The Z-actuators of the RPD were kept at approx. +20° C, while the Drill Head, Auger and Percussive Actuators were kept at approx. +50 °C. The bit temperature measured ~ -70 °C while cable harness was at -60 °C.

The goal of the tests was to capture six, ~10 cc samples from 40-50 cm depth, delivering them to six crucibles, and hermetically sealing. The first test followed the 10 cm 'Bite' approach, while during tests 2-6, the drill initially penetrated to 40 cm in a single 'Bite', was retracted to clean the hole, and lowered back in the hole to capture the 40-50 cm sample. This routine was used to speed up the sampling process.

The RPD successfully delivered six samples to the six crucibles. The average drilling power was 30 Watt (including actuator losses), Weight on Bit was ~10 Watt or less, while Penetration Rate was software limited to 2 mm/sec. Percussive actuator engaged only several times during the process, while majority of drilling was done with rotary approach, only. The bit temperature while the drill was in the hole was approximately – 80 °C and no temperature increase was observed during drilling indicating the thermal changes to the sample due to the drilling process were minimal.

The end to end sampling sequence consisted of drill deployment, sample capture, sample delivery, and crucible sealing took approximately 1 hr.

The data will be analyzed over the next weeks and published at AIAA SciTech.

Figure 3. Lunar Prospecting Drill mounted inside VF13 lunar chamber facility at NASA Glenn Research Center.

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