TRIDENT: THE REGOLITH AND ICE DRILL FOR EXPLORATION OF NEW TERRAINS. K. Zacny[1], G. Paulsen[1], Z. Mank[1], A. Wang[1], T. Thomas[1], C. Hyman[1], B. Mellerowicz[1], Z. Fitzgerald[1], A. Ridilla[1], J. Quinn[2], J. Smith[2], J. Kleinhenz[3], [1]Honeybee Robotics, Pasadena, CA, zacny@honeybeerobotics.com, [2]NASA Kennedy Space Center, FL, [3]NASA Glenn Research Center, Cleveland, OH.

Introduction: Lunar Resource Prospector (RP) mission is a reconnaissance mission tasked with identifying volatile deposits within the top one-meter layer in the Permanently Shadowed Regions or PSRs [1]. This rover based mission will utilize several contact and non-contact instruments as shown in Figure 1. The front mounted Neutron Spectrometer Subsystem (NSS) will perform localization of elevated H2 concentration, and in turn will pin point water deposits. These water-ice rich deposits will be sampled to a depth of 1 m by a drill, called TRIDENT (The Regolith and Ice Drill for Exploration of New Terrains). During drilling, TRIDENT will deposit cuttings on the lunar surface and these will be viewed by the Near InfraRed Volatiles Spectrometer Subsystem (NIRVSS). NIRVSS will remotely characterize hydrocarbons, mineralogical context for the site, and nature of water ice within the cuttings. This data will determine whether the sample should be captured and delivered to the Oxygen and Volatile Extraction Node (OVEN) coupled with the Lunar Advanced Volatiles Analysis (LAVA) subsystem. The OVEN Subsystem will heat the sample and transfer volatiles to the LAVA subsystem. LAVA will quantify volatile species using GC/MS.

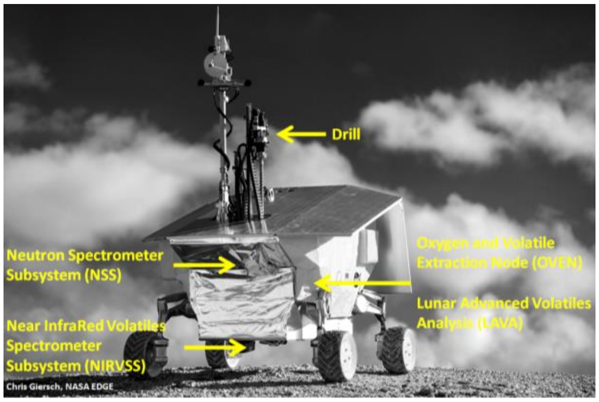


Figure 1: Resource Prospector Rover with the Drill

TRIDENT: The TRIDENT is based on the TRL4 Mars Icebreaker drill and TRL5 LITA drill developed for capturing samples of ice and ice cemented ground on Mars. It represents over a decade of technology development effort combined with analog field tests and vacuum chamber tests [2-4].

TRIDENT weighs approximately 15 kg and has combined power rating from its four actuators at just over 500 Watt. The drill has been designed to survivable temperature range from -233°C to +70°C. the lower thermal limit is driven by the temperature at PSRs.

The drill consists of: 1. Rotary-Percussive Drill Head, 2. Sampling Auger, 3. Sample Delivery Station, 4. Deployment Stage, and 5. Feed Stage.

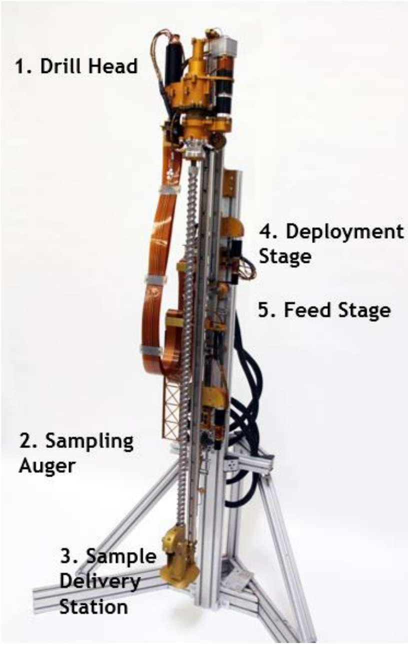


Figure 2: TRIDENT at TRL6

The drill head has two actuators to provide independent rotation and percussion. The 200-Watt auger actuator allows auger speed of up to 120 revolutions per minute and 14.9 Nm torque. Percussion is accomplished using a cam-spring design, based on Apollo Lunar Surface Drill (ALSD). The ALSD cam-spring mechanism has been modified to increase its efficiency and life, as well as make it vacuum compatible (ALSD drill head was pressurized with N2 for lubrication and heat dissipation purposes). Drill's percussive energy can be set for up to 4 Joules per blow at 1160 blows per minute. The drill is designed for 8.1 blows per revolution. The drill head has also an integrated slipring assembly for allowing integration of sensors inside the drill.

To reduce sample handling complexity, the drill auger was designed to capture cuttings and regolith as opposed to cores. High sampling efficiency and low drilling power has been achieved using a dual stage auger design (Figure 3). The lower section has deep and low pitch flutes, which are ideal geometry for retaining granular materials. The upper section was designed with shallow and high pitch flutes, which are ideal for efficiently moving cuttings out of the hole.

The auger lower section has an exposed RTD to measure regolith temperature during drilling process.

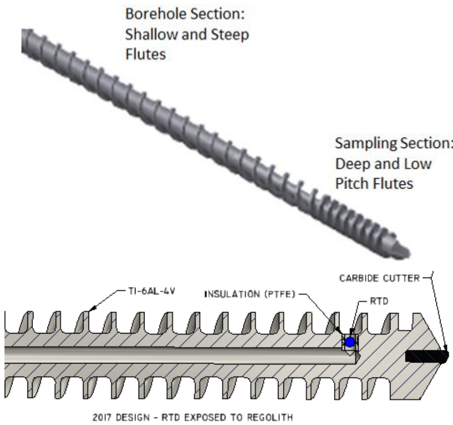


Figure 3. Dual stage auger with integrated temperature sensor.

The 25.4 mm (1 inch) diameter auger has been designed for “bite” sampling approach where samples are captured in ~10 cm intervals to a depth of 1 m (Figure 4). After drilling 10 cm, the auger with the sample is pulled out of the hole, and the sample is brushed off into ten-cc cups by a passive brush within the Sample Delivery Station. The brush forms a worm gear configuration with the auger – hence as the auger rotates, so does the brush. The bristles subsequently clear cuttings off the flutes, and these gravity fall through a funnel and either onto the surface or into a cup (depending on the requirement). There are numerous advantages of the “bite” sampling approach: stratigraphy is preserved because a sample comes from a known depth interval; since cuttings don’t need to be augered to the surface, the auger torque and in turn power is lower; the subsurface has time to cool off after drilling while the auger deposits samples into a cup above the hole; and all the analysis is done while the auger is out of the hole in its stored and save configuration.

The Deployment Stage is used to lower the drill to the ground and to preload the drill foot with 150 N force. Once the drill is deployed and preloaded, the rover does not see any drilling forces and torques – these are reacted internally within the drill system. This ‘preload and forget’ approach has significant operational advantage and is similar to the way Rock Abrasion Tool or Powder Acquisition Drill are deployed on Mars. The Feed Stage is designed to advance the auger below the surface just above the 1 m depth. The Feed Stage provides so called Weigh on Bit on the auger, and is software limited to 100 N. Both the Deployment and Feed stages are cable-pulley based for mass savings and dust tolerance. They are designed for up to 500 N of force (in any direction).

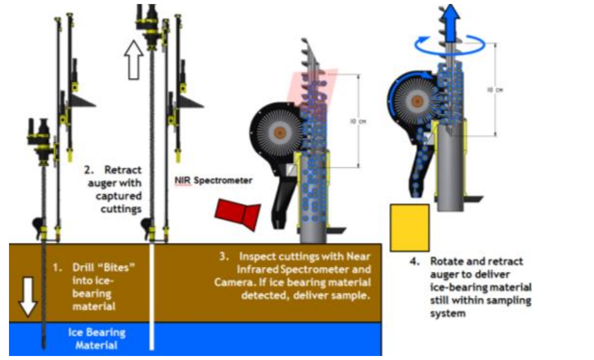
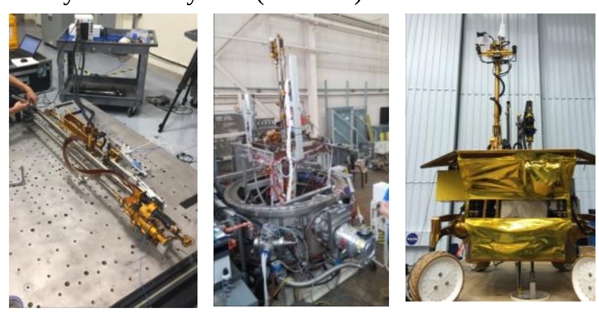


Figure 4. Implementation of the bite sampling.

TRL6 Qualification: To achieve Technology Readiness Level of 6 the drill has undergone several tests (Figure 5). These included Vibration tests at NASA KSC [5], Thermal Vacuum chamber tests at NASA GRC, and rover integration and end to end tests at NASA JSC. NASA GRC tests included drilling into NU-LHT-3M lunar soil simulant doped with up to 5wt% water and frozen to -160 °C (the cold wall temperature was -170 °C while vacuum was 10^-6 torr) [6]. NASA JSC tests included drilling on a lunar equivalent slope of 20° using the Active Response Gravity Offload System (ARGOS).



Vibration Thermal-Vac Rover

Figure 5. Achieving TRL6

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