DRILLING IN ICE BOUND LUNAR REGOLITH SIMULANT. G. Paulsen, K. Zacny, M. Maksymuk, J. Wilson, E. Mumm, J. Craft, K. Davis, and N. Kumar. Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com).

Introduction: Reaching the cold traps at the lunar poles and directly sensing the subsurface regolith is a primary goal of lunar exploration, especially as a means of prospecting for future In Situ Resource Utilization efforts. As part of the development of a lunar drill capable of reaching a depth of several meters, a preliminary drilling study was performed using custom designed drill bits and augers in simulated ice-bound lunar soil.

The tests were performed to 15cm depth in water-ice bound lunar regolith simulant. Results showed that it is possible to drill the hard regolith with modest power.

To enable testing to 1 meter depth in vacuum, a testing facility is currently being built, which includes rotary percussive drill system and 11ft tall vacuum chamber.

Drilling Apparatus: The drilling test equipment, shown in Figure 1, included an instrumented drill press, a test chamber that housed the test sample, signal conditioners, a digital display console, and a data acquisition and control system. The experimental arrangement allowed for remote control of the weight-on-bit (WOB) and the rotational speed of the drill string. Acquired data included weight-on-bit, rotational speed of the drill, reaction torque, (together converted to drilling power), depth of the bit inside the sample (converted to the penetration rate), bit temperature and the temperature of the drilled formation. During some of the drilling tests, the sample and the drilling chamber were cooled actively, either with dry ice, or liquid nitrogen flowing through a coil of copper tubing that surrounded the sample.

Drill Bits: Two designs of drill bits were tested, one with Tungsten Carbide Cutters (WC), and the other with serrated cutters made of Polycrystalline Diamond Compact (PDC). Both bits, shown in Figure 2, were made of annealed 420 stainless steel, had a central point made of WC, and cutters held in place by screw-clamped wedges. Thermocouples were imbedded in thermally conductive epoxy next to the leading edge of each cutter. The WC bit had the cutters placed at a rake angle of +5°, while the PDC cutters were placed at a rake angle of -15°.

Results: Drilled holes in the sample were extremely smooth with no amount of hole collapse (Figure 3). A summary of the drilling data is shown in Table 1. Initial tests were performed with rotational speeds upwards of 100 RPM in samples that were not actively cooled, or actively cooled to -60°C with dry ice. The rates of penetration for both the PDC and WC bits were quite high, but these could not be sustained because the augers clogged up with highly compacted cuttings which eventually stalled the progress of the drill. In these tests bit temperatures were also quite high. These tests proved that bit temperature is directly proportional to the drilling power (power being RPM x torque), as shown in Figure 4.

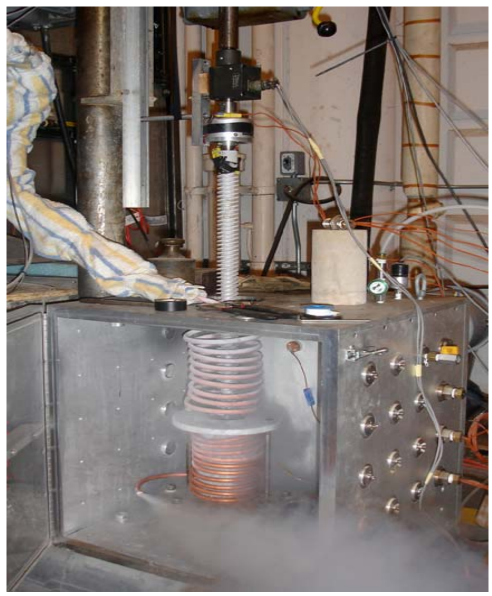

Figure 1: Drilling Test Equipment.

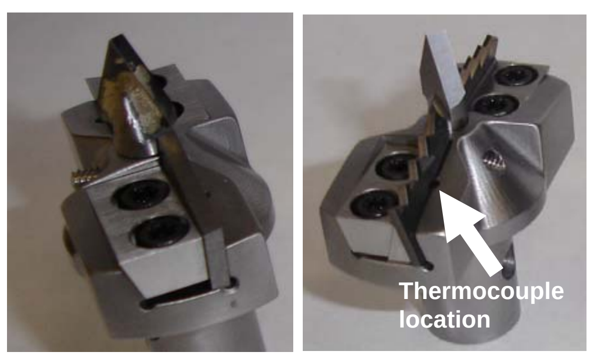

Figure 2: Drill bits used for drill study.

In subsequent tests, performed with active LN2 cooling (PDC bit) and without active cooling (WC bit), the rotational speed was reduced to 60 RPM and weight-on-bit (WOB) was controlled manually to prevent the bit temperature from exceeding -10°C. In these tests, the cuttings were not compacted in the auger, but maintained the form of a loose powder that was easily excavated from the hole.

A comparison of the performance of the PDC and WC bits at 60 RPM and a similar bit temperature of approximately -10°C shows that the PDC bit is more efficient (specific energy 169 MJ/m^3 vs. 212 MJ/m^3), but requires a higher WOB.

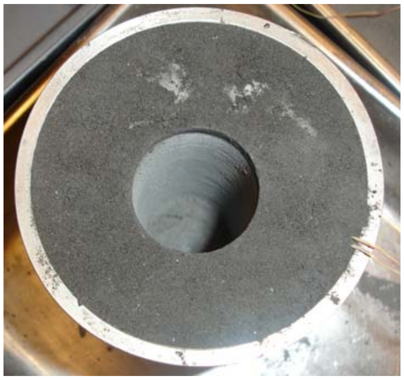

Figure 3: Hole in Lunar simulant appears stable.

Table 1: Summary of Drilling Results.

Bit Type	Active Cooling	Drill RPM	WOB	Drilling Power	Rate of Penetra-tion	Specific Energy (MJ/cm3)
PDC	None	100	180 N	30 W	40 cm/hr	238
WC	CO2	150	240 N	30 W	130 cm/hr	73
PDC	LN2	60	260 N	16 W	30 cm/hr	169
WC	None	60	120 N	10 W	15 cm/hr	212

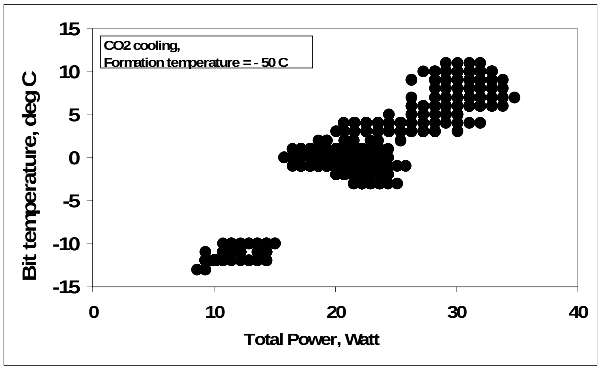

Figure 4: Bit temperature vs. Drilling power appears linear.

Future Work: Honeybee Robotics has been developing a rotary and a rotary-percussion drill system for planetary exploration. This is a test drill with a power rating of 1000 Watt, whose purpose is to test various drill bits and augers in rotary and rotary percussive operation. It is not optimized for power or mass but rather to acquire qualitative drilling data such as penetration rate, power, torque, temperature, Weight on Bit, vibration energy, and others. In addition, the design of the drill allows it to acquire drill bit temperature, torque directly at the drill bit, and other down-hole information. The drill is designed to have a 1 meter stroke.

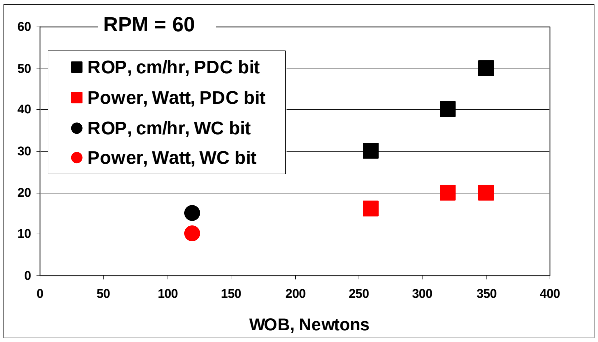

Figure 5: Comparison of power and ROP for PDC and WC bits.

In addition to the drill system, a matching split vacuum chamber, shown in Figure 6, (3ft wide, 3ft deep and 11 feet tall) will be delivered in early 2009. The chamber will be able to maintain pressure of below 1 torr. Maintaining sample temperature will be achieved by closed loop cooling system down to -40C or by using liquid nitrogen that allows a temperature of 77K.

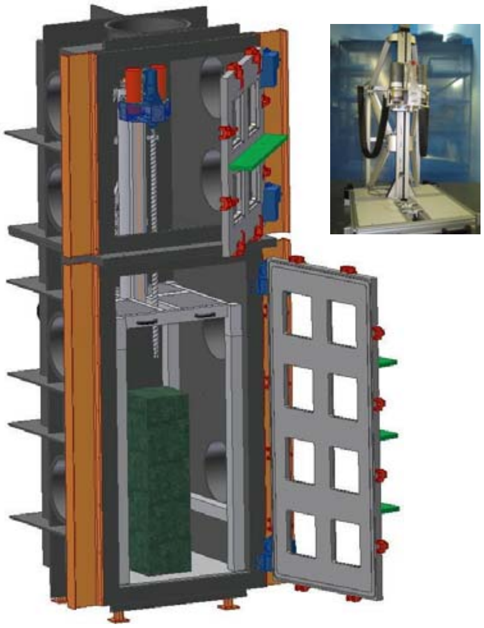

Figure 6: Split Vacuum Chamber with test drill.

References: [1] Zacny et al., Honeybee Robotics Planetary Drill Systems, LPSC (2008).