ROBOTIC COMPONENTS AND SUBSYSTEMS ENABLING LUNAR EXPLORATION: STATUS UPDATE. K. Davis[1], G. L. Paulsen[1], and K. Zacny[1], [1]Honeybee Robotics, 460 W 34th St., New York, NY 10001 (davis@honeybeerobotics.com)

Introduction: NASA is planning long-duration missions to the Moon starting by the end of the next decade. The extreme thermal and dust conditions of the lunar environment coupled with the need for reliable, long-life robotic devices challenges the current state of the art of space mechanisms. Honeybee Robotics is engaged in the development of various mechanical and electro-mechanical technologies on the component and subsystem level that will enable extended lunar exploration and habitation. This abstract provides an overview of this organization's relevant work and the status of the development efforts.

Componenet Level Technologies: Honeybee is developing a number of component level technologies that are applicable to robotic and robot-assisted lunar exploration. These include:

- Compact Gear-Bearing Transmissions for Cryogenic Long-Life Applications.
- Extreme Temperature Switched Reluctance and PM Brushless Motors.
- Extreme temperature Brushless Resolvers.
- Extreme temperature Brushless Slip-Rings.
- Quick-Insertion Fasteners for Rapid Robotic or EVA-compatible Assembly of Space Structures.
- Dust tolerant mechanical and electrical connections.

The Compact Gear-Bearing transmission, shown in **Error! Reference source not found.**, offers mass savings and reliability advantages of more conventional planetary and harmonic drive gear transmissions due to its simplicity. Materials and coatings work is under way to adapt the design for cryogenic-vacuum applications down to 40 Kelvin. This scalable mechanism is envisioned for a range of applications including robotic arm joints or excavator actuator transmissions. Prototypes have been tested in vacuum at a temperature of 110K.

Figure 1. Gear-Bearing Transmission Prototype

Extreme temperature motors and resolvers that operate at ambient temperature extremes as high as 460°C and pressures as high as 90 bar are also being developed. There is nothing that precludes the technology from also functioning well in vacuum and at the cold extremes. A switched-reluctance type motor, which does not use permanent magnets, has been developed and prototypes have demonstrated the capability to operate for hours (and potentially indefinitely) under these extreme conditions. Development of a extreme environment permanent magnet brushless motor and a brushless resolver is just beginning, see Figure 2 below. Honeybee plans a family of actuators and resolvers spanning the low to medum speed-torque range most commonly used by robotic mechanisms.

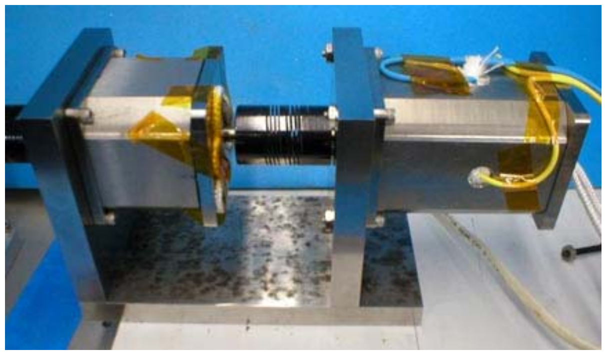

Figure 2. Extreme temperature motor and resolver

Running electrical power and data signals across a continuously rotating interface is a common challenge in many robotic devices. Honeybee is continuing development of its brushless slipring, shown in Figure 3**Error! Reference source not found.**, which is designed to reduce signal noise, wear, and particulate generation and improve heat dissipation, all issues that plague conventional brushed slip rings. The design features rolling contacts to transmit electrical power and signals through a continuously revolving joint. By virtually eliminating sliding contact, the life of the mechanism is increased.

Figure 3. BL Slip Ring

Quick and easy assembly methods will be essential to the construction of lunar outposts. The Quick Insertion Nut, shown in Figure **Error! Reference source not found.**4, was originally developed for NASA as an EVA-compatible structural fastening method that would also work for robotic on-orbit assembly systems. A compliant split-nut design allows for rapid bolt insertion while tolerating a high degree of misalignment during the insertion process. Less than one revolution is required to preload the joint. Honeybee is currently developing a concept for rapid assembly of spacecraft bus structures with the AFRL. The concept includes the Quick Insertion technology and provides a means for simultaneously making electrical and thermal connections.

Figure 4. Quick Insertion Fastener

One of the biggest problems in the exploration of the moon and other planets is the effects of dust on mechanisms. In the Apollo missions, dust quickly coated everything including the astronaut's suit, boots, gloves and other mechanisms they used to explore the moon.

Honeybee Robotics is in the early stages of developing reusable connection mechanisms capable of operating in a dusty lunar environment. The research carried out so far has concentrated on characterizing the problem, defining requirements and fabrication of several breadboard connector concepts. Additional work is focusing on mating features for self-assembling (robotic) mechanisms. The study includes experimenting with assembly techniques and geometries to minimize the failures induced by dust buildup in mechanisms.

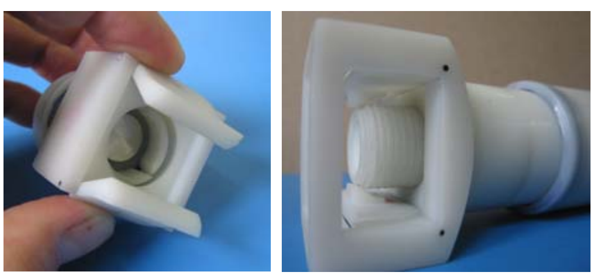

Figure 5. Dust Tolerant Connector breadboards

Subsystem Level Technologies: In addition to the component level technologies, complete subsystems have are also at various stages of development at Honeybee. These technologies include:

- Pneumatic Lunar Regolith Excavator.
- 2-meter Rotary Percussive Sampling Drill.
- Low-Reaction Force Regolith Digging Tools.

Two subsystems have been developed specifically for collecting and accessing lunar surface and subsurface material. The Pneumatic Lunar Regolith Excavator utilizes the flow of exhaust gases from a combustive reaction to collect regolith. Testing of a system that utilizes this process showed that approximately 3000 grams of lunar regolith simulant could be collected with only 1 gram of air. The second subsystem, shown in 6, is a rotary percussive sampling drill. The Construction & Resource Utiilization eXplorer (CRUX) drill was designed for penetrating a water ice/lunar regolith mixture to a depth of approximately 2 meters. The drill was designed to carry a sample acquisition mechanism as well as down-hole instruments (e.g., mechanical properties probe, spectronmeters). This research took place in 2005 with the US Army CRREL. Honeybee is currently seeking funding to continue development of the CRUX drill.

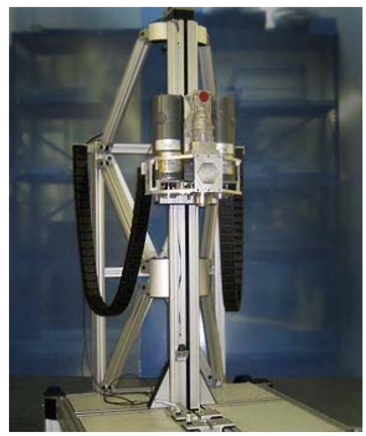

Figure 6. CRUX rotary percussive sampling drill.

Honeybee is also beginning development a robotic-arm based Low-Reaction Force Regolith Digging Tool. This tool utilizes percussive technology to penetrate strongly cemented regolith with very little reaction force provided by the robotic arm. The work builds on the recent development of an Icy Soil Acquisition Device (ISAD) for the 2007 Phoenix Mars Lander.

Figure 7. 2007 Phoenix ISAD