TELESCOPIC / PNEUMATIC HEAT FLOW DEPLOYMENT FOR THE INTERNATIONAL LUNAR NETWORK MISSIONS. K. Zacny[1], E. Mumm[1], P. Fink[1], W. Henrnandez[1], G. Paulsen, and M. Maksymuk[1]. [1]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com);

Introduction: Measuring internal heat flow (i.e., heat flow that originates deep within the interior of the Moon) tells us about the origin of the Moon and its composition. If we know the age of the Moon, then the heat flow will reveal if it had a hot or cold origin. In addition, heat flow will reveal information on the bulk structure and composition of the Moon relative to heat producing elements (radioactive 40K, 232Th, 235U and 238U) and the extent of crystal differentiation.

The shallow subsurface temperature of the Moon is strongly influenced by the diurnal, annual, and precession fluctuations of the insolation. Therefore, the best way to measure the internal heat flow is to insert a probe to a depth beyond the reach of the surface fluctuation. Such depth is considered to be 2 (below diurnal and annual influence) and 5 to 7 m (below influence of precession) [1].

The heat flow measurement directly addresses one of the main science objectives of the International Lunar Network missions.

Methods of Deploying Heat Flow Probe: There are a number of ways the heat flow probe can be deployed. These methods differ in many ways such as simplicity and mass of the deployment system, power required to deploy it, thermal isolation between temperature sensors and between sensors themselves and surface system (deployment system, lander, electronics box etc), and methods of deployment (astronaut vs. robotic).

The possible methods may include: 1) Drilling a hole, pulling the drill out (holes on the Moon up to 3m depth do not collapse) and lowering a heat probe into it; 2) Drilling a hollow, low conductivity casing and lowering a probe into it (Apollo approach); 3) Drilling a probe into the regolith (the probe is integrated into drill rods); 4) Hammer the drill rods with probe inside them into the regolith by using either a top hammer system or a mole approach.

Pneumatic system with telescopic deployment: This system consists of a percussive head (pneumatic or electromechanical hammer), telescopic deployment system, and a string of thermal sensors/heaters mounted to a spring loaded anchors and connected to each other by a string (Figure 1 and Figure 2). During probe emplacement, the sensors would be stored in the hollow tube (Figure 3).

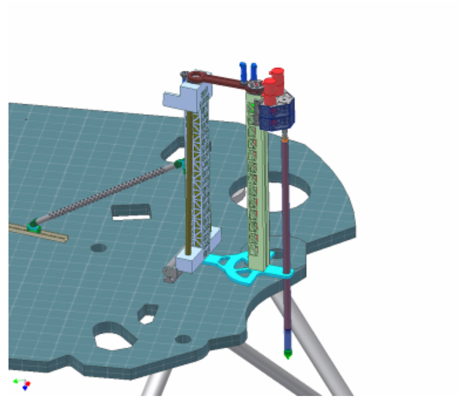
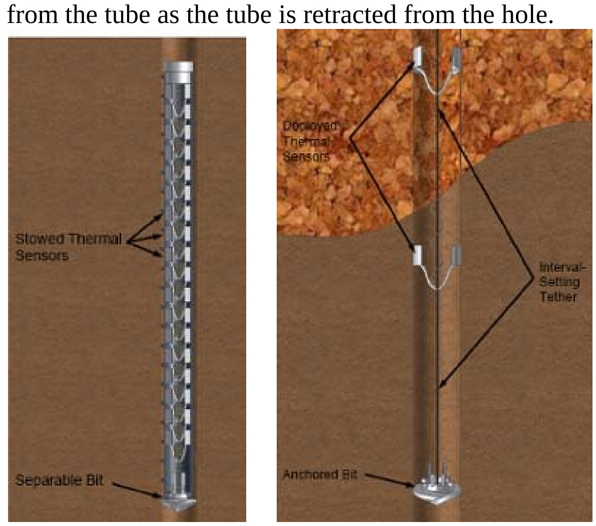


*Figure 1**: The heat flow probe. The system consists of a deployment stage, percussive head, telescopic rod with a sensor tube and an anchor/cone at the end.***

The probe assembly will be driven into the subsurface using a percussive actuator with assisted helium cuttings removal. In the proposed solution, the cone mounted at the end of the tube would separate from the lead string and be left behind as an anchor for the sensor string. The sensor string would then be deployed from the tube as the tube is retracted from the hole.



Thermal sensor anchors stowed within the penetrometer.

Separable cone/bit deployed as a thermal sensor string anchor

*Figure 2**: Thermal anchor deployment method.***

Although the rotary-percussive drilling approach to penetrating lunar regolith was proven effective during the Apollo experiments, we believe that a pure percussive approach will make the heat flow probe deployment simpler for robotic landers. The percussive penetrometer uses high-frequency and low-energy impacts to penetrate the regolith. When a rod is inserted into regolith, the resistance to insertion comes from two sources: regolith being displaced/crushed ahead of the probe and regolith sliding against the rod as it is being inserted. (The latter is referred to as sleeve friction.) The combination of high-frequency and low-energy percussive impacting reduces both resistance forces. The regolith ahead of the pointed tip of a penetrometer becomes displaced, packed, and crushed due to the vibration; this allows the cone to penetrate deeper. Simultaneously, the regolith rubbing against the penetrometer surface continuously vibrates and reduces the sleeve friction; this makes insertion of the penetrometer relatively easy.

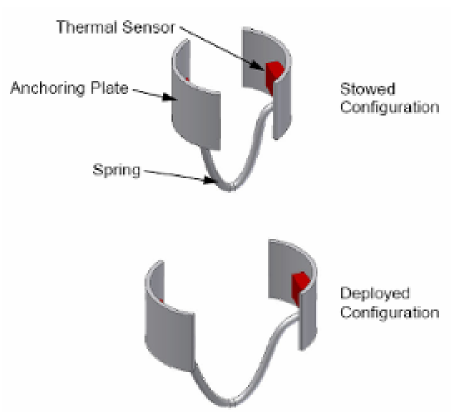


*Figure 3**: Individual thermal sensor emplacement anchors shown in stowed (top) and deployed (bottom).***

Use of helium to remove regolith and power pneumatic hammer: Helium gas is used to pressurize propulsion tanks. After touch down, there is ample of gas left that can be tapped into and use for either air hammer and/or blowing the regolith out of the hole.

We used COTS pneumatic 0.5 hp hammer driven by 40 psi air and 40 psi helium to drive 1in diameter rod with 30 degree cone into a compacted to 1.9 g/cc JSC-1A.

Prior to tests, the regolith penetration resistance was tested with a push penetrometer. It was found that a combination of high density and small diameter (~4in) test cylinder (rigid walls) resulted in penetration resistance of >11 MPa, which was more than 6 times higher than the penetration resistance of the in-situ lunar regolith. Thus, the soil sample was adequate for simulating lunar conditions.

When using helium gas for powering pneumatic hammer, a depth of 24 inches was reached in 22 seconds. A total of 8 grams of helium gas was used. When using compressed air, a depth of 24 inches was reached in 15 seconds. However, 68 grams of air was used. The penetration rate in both cases was constant and thus, the data can be extrapolated to 3 m depth. Taking into account losses, inefficiencies, margins etc., it is anticipated that 0.5-1kg of compressed helium may be required for the pneumatic hammer.

We have also shown that by removing the regolith from the hole, it is possible to drastically reduce the force required to push the rod into the hole. In preliminary tests a 1 inch diameter cone was pushed 2 inches into a regolith with 100 lb of vertical force before the penetration stopped. However, when helium gas was injected below the cone (via an injector holes in a cone as shown in Figure 4) the vertical thrust force became zero (essentially the rod was falling into the hole under its own weight) and the rod reached the maximum possible depth of 25 inches. Only 9 grams of Helium at 5 psi (19.5 pisa) was used.

*Figure 4**: Cones with injector nozzles. Top left: 4 injector nozzles around the tip of the cone; Top right: central injector nozzle replacing the tip of the cone.***

Advantageous of the system: The proposed method offers many advantages including:

- Optimum thermal isolation between consecutive heat flow sensors
- Thermal isolation between sensors and a lander platform/deployment system,
- Direct contact between the sensors and regolith,
- Simple and robust deployment method that does not rely extensively on lander mass but instead takes advantage of the remaining helium gas from the propulsion tanks for powering the percussive head and for blowing chips out of the hole (and in turn reducing required preload).

Other advantages include potential for low power operation (which reduces heat flow input into the formation), potential for small volume, and low mass. In addition, all of the electrical connections can be established prior to launch, thus there will be no need for additional actuators on the Moon or for mating electrical connections in the dusty lunar environment.

References: [1] Wieczorek, M. A., and S. Huang, 2006, A reanalysis of Apollo 15 and 17 surface and subsurface temperature series: Lunar and Planetary Science Conference, p. 1682.