THERMAL SENSORS AND DRILLING SYSTEMS FOR LUNAR AND PLANETARY REGOLITH

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Introduction: The thermal conductivity of planetary near surface layers is a key parameter for describing the energy balance of many solar system bodies like airless moons, asteroids and comets.

These bodies are often covered by so-called regolith layers, which are known to be very good thermal insulators. The best-known example is the surface of our Moon, which is up to now the only extraterrestrial body where some in situ measurements have been done, although only a few and in a rather crude way. For future lunar lander missions accurate thermal conductivity measurements in deep drill holes are of high interest. However, due to the very low conductivity values to be expected routine methods available off the shelf (like e.g. the standard thin wire method) are not directly applicable, respectively need further development and modification.

Moreover the drilling of deep (and slender) boreholes in the lunar regolith is necessary. This demands novel drilling techniques which can cope with low gravity environment and minimize power, mass and volume requirements. As an example we discuss in this paper a ‘‘woodwasp’’ drilling system recently developed at the University of Surrey (England), which may allow deep drilling (1–2 m) into the lunar surface at moderate power and mass expenses.

Thermal sensors for low conductivity materials:

Standard heated wire sensors as described above are suitable for measurements within a reasonable conductivity range. Under terrestrial conditions (1 bar air pressure) they are suitable for most materials, also those with a loose, powdery texture, because the air in the pores improves the thermal contact to the sensor. For example, the sensors used for the measurements discussed in the previous section would give inaccurate results when used in a medium with k _ 0.1 Wm_1 K_1, because the influence of the sensor properties itself becomes too big and too little heating power can flow azimuthally through the medium to be measured. In terrestrial laboratory and field experiments it is always possible to improve the thermal contact artificially by surrounding the needle by a heat conducting gel to close the gap between needle and borehole wall. However, for powders in vacuum the situation becomes much more stringent, especially if measurements have to be done on a remote place by a robotic system. Due to the lack of the air in the pores and a small contact area (Hertz factor) of the particles their thermal conductivity can be orders of magnitude smaller than under air conditions. These facts are known for a long time, both from laboratory tests with powders under vacuum and from the few direct measurements in the lunar .

Thermal conductivity measurements in various regolith analog samples: (a) reddish fine-grained dune sand from the Lanzhou region (Gansu, China) which may resemble the sand covering the surface of Mars; (b) cm-sized roundish gravel. The heated wire sensor used to evaluate the thermal conductivity is embedded in the respective samples, its upper part (atop the heated needle) is visible. These measurements were performed under air pressure and isothermal conditions (20 _C) in a climate chamber. The visible part of the thermal conductivity probe has a diameter of 1 cm, the inserted heated needle is only about 2 mm thick and 15 cm long.

Still we think that dynamic methods like the heated wire probes are best suitable to be employed on a routine basis for measurements of the soil’s heat conductivity on lunar lander and rover missions, because they are fast and flexible and need little interference by an operator, except that a borehole must be provided. However, as compared to sensors used in terrestrial measurements, there are mainly two problems that have to be solved: (i) how to overcome the low thermal contact between the sensor and the borehole wall, and (ii) how to avoid that a significant part of the heat is released along the sensor itself.
To solve the first problem, two concepts may be suitable: first, the thin steel needle representing the heated sensor can be surrounded by a sort of wire brush, which builds local bridges to the surrounding borehole wall in lateral direction, while in vertical direction the heat flow is largely blocked. Due to its flexibility this will not hinder the insertion of the sensor into the borehole, but it should significantly improve the thermal contact of the heated needle to the surrounding medium during the measurement.An alternative design would be a sort of inflatable structure, into which heating wires are incorporated. In this case insertion and extraction of the sensor could be done in the deflated state, so that the motion inside the borehole is not hindered, but during the measurement the structure could be inflated by an attached gas reservoir in order to press its outer surface against the borehole and thus insure a good contact. To allow for a repeated use in different boreholes, a movable piston must allow to vary the volume of the ‘‘balloon’’ in order to in-

flate and deflate it in a controlled way. Both concepts will, of course, lead to some deviation from the thin wire geometry, and the consequences need to be considered carefully by thermal modelling.

Novel drilling concepts:

Thermal sensors as described above are only useful in combination with an appropriate drilling technique. A tentative overall configuration (for example onboard a lunar rover) could be a centrally mounted carousel with one opening hole for access to the soil. The single ports would include first of all a drilling system for creating a borehole and possibly also transporting the material produced by the boring process to a suitable instrument for chemical analysis. After the borehole has been created and the drill cores have been removed, the carousel rotates to allow other instruments to investigate the borehole, among them the thermal sensor. For thermal measurements and even more for intrinsic heat flow measurements the created borehole should be slender and deep.

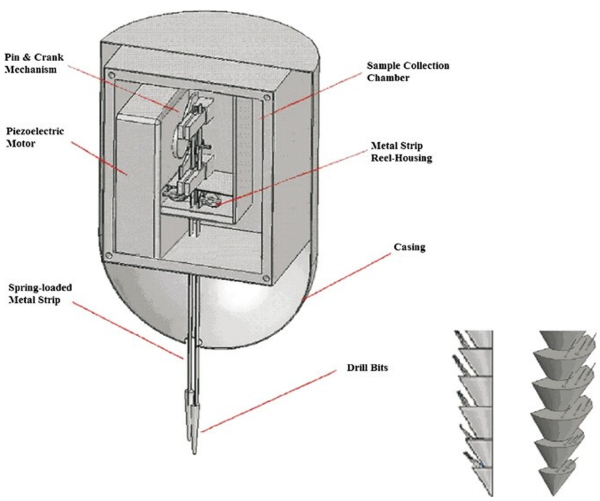

Figure: Concept of a novel drilling system that might be suitable for creating thin and deep boreholes in the lunar regolith, which are a prerequisite for implementing thermal conductivity and heat flow sensors

A diameter of the order of 1–2 cm and a depth close to 2 m may be a reasonable design goal. We note that the borestems used during the Apollo missions were hand-operated and quite heavy. Also the diameters of the drilled boreholes were larger than 2 cm .In the upcoming lunar lander and rover missions space and power requirements will probably be more stringent than for the Apollo missions. Recent developments have brought up novel drilling concepts that may be better suitable to be used in combination with thin wire thermal conductivity sensors on the Moon.

References:

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