Stirling Power Generation for Lunar Polar Lunar Day/Night Use

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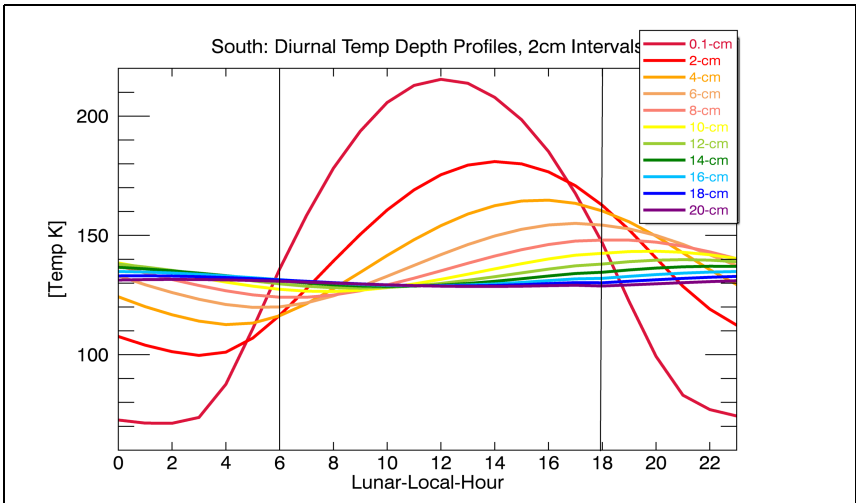

Figure 1 shows the temperature gradient within the lunar regolith as a function of lunar-time-of-day near the Moon's South Pole. Beginning at midnight (hour 0), the surface is very cold (~70K), but the temperature below 10 cm is ~135K and stays almost constant for the entire lunar day. For long periods of the night, there is a very large temperature difference (~60K) between the surface and the regolith at 10 cm (5 inches) depth. During the lunar day there is a reverse temperature gradient (~85K) where the surface attains a high temperature of ~220K at noon, while staying ~135K below 10 cm depth. ***Our proposed Stirling power generator will take advantage of the naturally occurring temperature differences during the lunar day and night to generate power for surface Moon missions.*** The plot is derived from LRO Diviner infrared temperature models of the lunar subsurface showing the temperature variation at depth.

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Introduction: We plan to design an advanced power generator system that takes advantage of the temperature differences (see **Figure 1**) between the Moon's surface and the thermal reservoir of the regolith below 10 cm to power an efficient cryogenic Stirling electric generator. Compelling lunar science are severely compromised by power limitations imposed by the long lunar night, thus limiting their scientific lifetime and value. The decadal survey lists several compelling lunar missions to the South pole Aitken Basin, Lunar Resource Prospector, and the Lunar Geophysical Network as future opportunities that would be more valuable if they could survive the 14.5 earth days without power. Even with efficient batteries, such power

limitations significantly constrain nighttime operations to that of a survival mode while nuclear power sources are prohibitively expensive. Our design will **enable** *in situ* investigations of the Moon for subsurface water in the permanently shadowed regions or for long duration surface missions that need to operate and survive the entire duration of the Moon's diurnal cycle.

The unique contribution of this proposed development is to leverage the naturally occurring heat differences between the surface and some distance at depth during the Moon's day to power a Stirling generator. Much work has already been performed to optimize Stirling power generation for space use. However, NASA has recently stopped work on the Advance Stirling Radioactive Generator (ASRG) that was once touted as an enabling technology for deep space missions. Our idea makes use of new information about the Moon's highly insulating regolith and temperature distribution derived from LRO Diviner surface measurements.

We aim to determine:

1) How much power (goal of 100-200 W) can we generate with the predicted heat difference between surface and depth and with a moderate sized generator? Which Stirling design can be used to optimize power generation, e.g. free piston design, helium gas as the active fluid, linear electric power generator, etc;

2) What design elements are needed for efficient operation at the temperature ranges predicted during the lunar day and night.

3) If we need to fabricate a prototype or adapt an existing model and to test in a cryo-chamber and to simulate operation at the Moon to verify design performances.

All currently planned surface missions to the Moon are limited in duration by the need to generate power during the lunar day thus limiting mission duration to 14 Earth days maximum. These missions include the New Frontiers sample return mission at the South Pole-Aitkin Basin, *Moonrise*, and the polar volatiles explorer, *Resource Prospector*. The *Lunar Seismic Network mission* concept would require radioisotope power generators to field 8-10 seismometers around the Moon. A thermal gradient Stirling power generator can add additional scope to *Moonrise* and *Resource Prospector*, and it can enable the *Lunar Seismic Network* without the prohibitively high cost of radio-isotope power generators.

This development has distinct advantages that differ from previous ideas such as:

http://www.slideshare.net/mattkopecki/design-of-a-power-generation-system-for-lunar-applications-10687669
http://ntrs.nasa.gov/search.jsp?R=20060028456 or
http://science.nasa.gov/science-news/science-at-nasa/2009/15may_stirling/
http://phys.org/news/2013-12-electricity-moon-night.html
http://www.powermag.com/using-the-sterling-engine-for-solar-and-lunar-power/