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Investigation for the precise measurement method of lunar and planetary heat flow and development of heat flow probe

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The precise measurement of lunar and planetary heat flow is an essential method for constraining their internal temperature distribution, thermal history, and material composition. Besides the Earth, the in-situ measurements were only conducted in the Apollo 15 and 17 missions on the Moon. About 20 years later from the Apollo missions, a high speed penetration probe (so-called penetrator), developed at Institute of Space and Astronautical Science in Japan, has an advantage that the heat flow measurements can be conducted at many sites at once mission. However, because the heat flow measurement devices on board a penetration probe including the probe of Apollo mission and penetrator are exposed on the regolith, they are easily influenced on the thermal distribution of the regolith varying from the heat conduction of the penetration probe. Therefore the heat flow measurement devices have the uncertainty for determining the planetary intrinsic heat flow value.

In this study, we investigate the thin heat flow probes which can be extended from surface of the penetration probe to a point indicating more intrinsic heat flow value of the planet (requirement of accuracy: better than 10%). On this presentation, we report the result of comparison investigation with the accuracy of heat flow from the measurement principle of thermal conductivity and thermal gradient and the numerical simulation based on the model of penetrator, and the accuracy of heat flow measured by the developed heat flow probe.

From the measurement principle and the numerical simulation, in case of the heat flow probe which has several sensor points, the two of their sensor points are tip of the probe which is the most accurate position of thermal gradient, and center of the probe which is the most accurate position of thermal conductivity. The accuracy of heat flow at these points is found to be 2.4% on the lunar regolith, and 1.9% on the martin regolith. In addition, we constrained the variety, length, and diameter of the probe material as considering the accuracy of heat flow and the strength of heat flow probe extending to regolith.

From restriction of development of heat flow probe, we made the heat flow probe of multiple sensor point, and conducted the experiment of heat flow measurement of glass beads at atmosphere pressure and vacuum. As a result, at atmosphere pressure, when the sensor point is from center to 3cm from center of the probe, we can accomplish the requirement accuracy of thermal conductivity (about 5%). When the sensor point is center of the probe, the best accuracy of thermal conductivity was determined to about 1.8%. On the other hand, at vacuum, comparing with the thermal conductivity by the heat flow probe and by line heat source method, the relative error of about 35-84% occurred when the sensor point is from 1cm to 3cm from center of the probe. Therefore the accuracy of thermal conductivity from the experiment of the heat flow probe was found not to be consisted with that from the measurement principle of thermal conductivity at vacuum.

To distinguish whether these error were caused by the glass beads or the heat flow probe, we measured rise profile in temperature of air which is more uniform distribution of thermal conductivity than that of grass beads. In the result, we found that the error at 1,2cm from center of the probe was caused by the probe, and the error at 3cm from center of the probe was caused by the glass beads. As future work, this error cause is required to discuss quantitatively to determine the measurement accuracy of heat flow probe at vacuum.

Keywords: heat flow, moon, planet, regolith