In situ lunar heat flow experiment using the LUNAR-A penetrator

Conference or Workshop Item

How to cite:

Tanaka, S.; Yoshida, S.; Hagermann, A.; Hayakawa, M.; Fujimura, A. and Mizutani, M. (2001). In situ lunar heat flow experiment using the LUNAR-A penetrator. In: 32nd Lunar and Planetary Science Conference, 12-16 Mar 2001, Houston, Texas, USA.

Link(s) to article on publisher's website:
http://www.lpi.usra.edu/meetings/lpsc2001/pdf/1495.pdf

IN SITU LUNAR HEAT FLOW EXPERIMENT USING THE LUNAR-A PENETRATOR .

S. Tanaka, S. Yoshida, A.Hagermann, M. Hayakawa, A. Fujimura, and H. Mizutani;Institute of Space and Astronautical Science,Yoshinodai, Sagamihara Kanagawa, 229-8510, Japan

Introduction: An in situ lunar heat flow measurement is planned using the Japanese LUNAR-A penetrators which will be deployed on the near and far side of the lunar surface in the year 2003. The penetrator is a cone shaped probe which is 0.84m in length and 0.16m in maximum diameter[1]. The lunar heat flow is of vital importance in lunar science, because it provides a basic data for inferring the thermal state of the lunar interior and also a strong constraint of bulk abundance of radioactive elements in the moon. Recently, the thorium abundance of the whole lunar surface area has been reported from the gamma ray remote sensing observation[2]. The most feasible candidates of landing sites of the two penetrators are near the Apollo 12 landing site and almost at the center of the Mendellev crater. The thorium abundance of A12 site has a concentration 2.5ppm larger concentration compared with the A15 site(3.6ppm); on the other hand, the Mendellev site has an abundance 1.5ppm smaller compared with the A17 site(1.9ppm). The relationship between the thorium abundance and the heat flow data of such a wide range of thorium abundance will give us better estimation of the averaged heat flow value.

Sensors for the measurement of heat flow by the LUNAR-A penetrator: The penetrators contain 17 temperature sensors (Fig. 1). Seven of these are absolute temperature sensors made of platinum resistance wires and eleven are type-K thermo-couple sensors for the measurement of relative temperature. Five of the eleven thermo-couple sensors are attached to small sheet-shaped heaters which are used to heat the regolith to measure its thermal conductivity/diffusivity. The temperature change of the regolith upon supplying a heating power of 50mW for 120sec will provide the data of the thermal conductivity of the regolith[3,7]. The relationship between the thermal properties and the temperature change has been calibrated well and the accuracy of determination of the thermal conductivity with this method is found to be about 10 %. All the relative temperature sensors are mounted on or near the surface of the body for the purpose of the heat flow measurement. On the contrary, four of the five absolute temperature sensors are mounted inside the penetrator for the purpose of house-keeping the electronics or batteries.

The resolution of temperature is an important specification for the temperature gradient measurement. Considering both the results of numerical simulations and technical feasibility, we designed the hardware to obtain 1/100 degree resolution for the relative temperature measurement. With this resolution, we will be able to determine the temperature gradient within about 10% error.

Temperature field around the penetrator: Since the thermal properties of the penetrator and that of the regolith are significantly different from each other, the temperature field in the regolith around the penetrator is expected to be disturbed significantly from the original one by placing the penetrator itself in the regolith. For example, the thermal conductivity of CFRP (Carbon Fiber Reinforced Plastic), which is a main component of the penetrator's body, is about 4.2 W/m/K, whereas that of the lunar regolith is about 0.01 W/m/K[4]. Therefore the penetrator will become a major heat path for the lunar heat flow, changing the temperature gradient to a value lower than the original temperature gradient. Figure 2 shows a temperature contour map around the penetrator based on the assumption of suitable thermal properties of each component of the penetrator and the 1deg/m temperature gradient of the regolith. The result shows that the temperature difference gradient measured on the surface of the penetrator body is reduced to 1/10 compared to the original temperature gradient in the regolith.

Precise thermal model of the penetrator: It is essential to quantitatively correct the thermal disturbance caused by the penetrator to infer the original temperature field. In order to correct for the thermal disturbance, we need to construct a precise thermal model of the penetrator by using measured thermal conductivity, specific heat, and density of every component of the penetrator. The thermal conductivity, specific heat, and density of every component of the penetrator were measured by a stationary method within 10 % error [5]. In order to refine the thermal model of the final model, a fully integrated penetrator was suspended in a temperature control unit 1.5m in height and 0.5m in diameter. The unit was placed in a large space chamber 4m in height and 4m in diameter[6]. The space chamber was evacuated to below 10^{-5} Pa, and was cooled to a temperature of 77K. We modified the initial thermal model to fit the temperature data obtained during cooling. When adjusting the thermal properties of our mathematical model to fit this temperature data, we allowed for a 10% change for those materials that had been measured on component-level and for a 20% change for components not measured experimentally. With this constraint, we found good agreement between the obtained data and the expected temperature profile. On the basis of the experimental data, we calculated the temperature disturbance of the penetrator placed in the regolith by changing thermal properties of components within the range of their uncertainties. It should be noted that the effect varies with the observation timing after the penetration because the difference of initial temperatures between the penetrator and the regolith (20 degrees assumed in this case). For earlier observation, the errors are induced by both thermal conductivity(K) and heat capacity because the penetrator is still in the transient cooling phase. After 30 days, only the effect of K becomes dominant since the penetrator has nearly reached its steady state. Among the error contribution factors, the axial conductivity of CFRP body gives about as high as 4% an effect ,and a 12% error is expected on estimating the original temperature gradient in total when we observe the temperature of the penetrator 10 days after their penetration.

References:[1]Mizutani et al.(2000) ESA **SP462** 107 [2]Lawrence et al.(2000) JGR **105** 20307 [3]Horai et al. (1990) Proc. Lunar Planet Symp 277 [4]Langseth et al.,(1976) LPSC 3143 [5]Yoshida (1999) Ph.D thesis, University of Tokyo [6]Tanaka et al. (2000) ESA **SP462** 187 [7]Hagermann et al.(2001) LPSC(This issue)

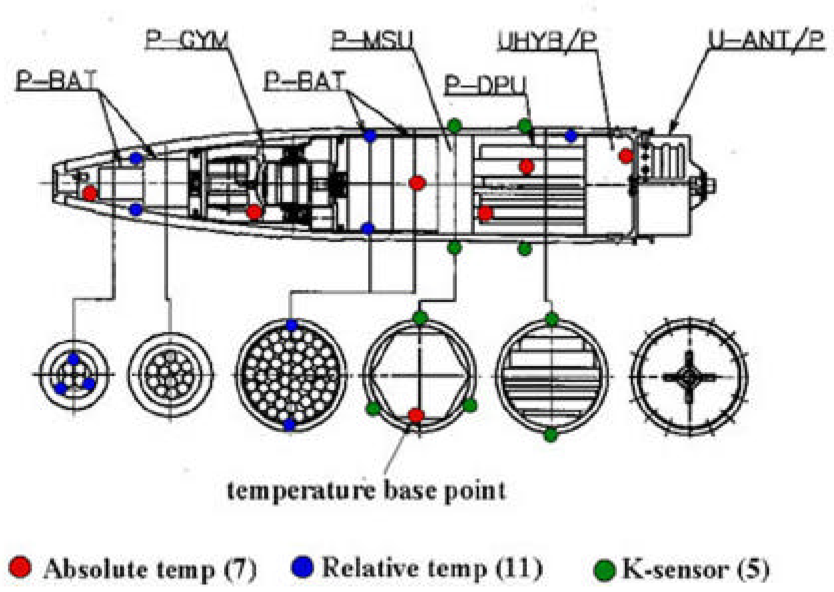

Figure 1. Schematic cross section of the penetrator and position of the temperature sensors and thermal conductivity sensors in LUNAR-A penetrator. The figure also schematically shows the schematic mechanical components; P-BAT: battery block, P-GYM: seismometer mounted on a rotational mechanism, P-MSU and P-DPU: electronics circuit blocks, UHYB/P: hybrid circuit for Tx and Rx, and U-ANT/P: antenna.

Figure 2. Steady state temperature distribution around the penetrator surrounded by lunar regolith. The interval of temperature contour is 0.02degree. The temperature gradient of the lunar regolith is assumed to be 1 deg/m. The ogive shape penetrator has a length of 800mm and 15cm in diameter, and weight of 13.5kg.