Performance of the shock-induced seismometer onboard the LUNAR-A penetrator

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The Japanese lunar penetrator mission LUNAR-A of ISAS (Institute of Space and Astronautical Science)/JAXA aims to study the lunar interior by using seismometers on board the lunar penetrators. Two penetrators will be deployed on the lunar surface by hard landing: one on the nearside, and another on the farside. At the impact on the lunar surface, the penetrator will receive a shock of about 8000G, even if the lunar surface is covered by a thick lunar regolith. The seismometer must secure the shock durability to retain its characteristics for the observation on the moon after the penetration. To verify the shock durability, we conducted the shockproof test for the LUNAR-A seismometer in the Sandia National Laboratory, New Mexico. The penetrator is projected by a Davis gun and penetrated into the target regolith of lunar simulant. When it impacts to the target, the seismometer experiences the impact shock, whose level is severer than that of the shock expected to be realized at the impact of the penetrator on the lunar surface. From an analysis of calibration waveforms obtained before and after the shockproof test, we found that the characteristics of the seismometer did not change significantly. The seismometer preserves the required physical characteristics for the larger oscillation after the impact shock of 8000G to 10000G for ~20msec.

It is required to ensure that the LUNAR-A seismometer can detect and measure the deep moonquakes after the penetration. The deep moonquakes have very low amplitude compared with seismic events of the earth. The seismological noise, ground motion or micro tremor of the earth is of considerable level, although the level of the ground motion in a quiet seismic observatory consists with the level of some deep moonquakes. To verify the dynamic response of the shock-induced seismometer for small oscillation corresponding to deep moonquakes, we select the Inuyama Seismic Observatory of Research Center for Seismology, Volcanology and Disaster Mitigation, Nagoya University, as the test site, where the level of artificial noise is very low and the level of micro tremor (1E-7~1E-8 m/sec in terms of the velocity of ground motion) consists with the maximum amplitude of some deep moonquakes.

In the tunnel of the Inuyama Seismic Observatory, the micro tremor is observed by the shock-induced LUNAR-A seismometer (removed from the penetrator). The observation with the reference seismometers is also achieved at the same time. As the reference seismometers, we used three types of seismometers: the STS-2 broadband seismometer the L-4 (Mark Product) geophone, and the conventional flat-spring seismometer (L227-25). From the results of the observation, we found that the dynamic response of the seismometer was consistent with that of reference seismometers for micro ground motion.

Next, we conducted the observation test by the shock-induced seismometer on the penetrator and the seismometer removed from the penetrator at Inuyama Seismic Observatory. The gimbals mechanism of the penetrator is used to reorient the seismometers to the desired direction by two-axis motors. The seismometer is sustained by a friction wheel and two opposing bearings in the gimbals. The seismometer will be received the oscillation of ground motion component and the other component reflecting the elastic properties of the gimbals mechanism, especially of the friction wheel and of the bearings. In the case of the strong oscillation, the seismometer may slide at the friction wheel. We compared the observed signals by the two LUNAR-A seismometers, one is on-board the penetrator, and the other is removed from the penetrator. From the results, we may deduce the effect of gimbals. We will discuss about the expected results on the observation of moonquakes by using the presently developed seismometer on board the penetrator.