Seismometer System for the Future Lunar Exploration

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Abstract. In Japanese LUNAR-A mission, a penetrator-based deployment of a seismic station would be planned. Each penetrator contains two-axis seismometers, which are installed inside gimbal system. The seismometer developed has higher sensitivity than short-period sensors used in terrestrial seismology even though its size is very small and light-weight. And also, we have confirmed that both the flight-type seismometer and its gimbals mechanism work well after impact penetration and that they can precisely measure the seismic waveforms of the terrestrial micro tremor, which is equivalent to the maximum amplitude of deep moonquakes.

The seismometer onboard the LUNAR-A penetrators is a short-period electromagnetic type with a natural period of about 1 second; the output is proportional to the relative velocity between a moving coil and an internal magnetostatic field. Its size is 50 mm in diameter, 50 mm in length and 350 g in weight. Though the principle of sensing is the most traditional type as a short-period sensor, its size is much smaller than sensors used in terrestrial seismology, whereas the sensitivity is much higher. Including the sensor electronics, the LUNAR-A seismometer is designed to be 3 to 5 times more sensitive than either the Apollo short-period and long-period seismometer at a frequency of around 1 Hz (Latham et al., 1969). In spite of the present small size and light weight, it is generally supposed to be extremely difficult to realize such a long natural period and a high sensitivity. Therefore, some technological innovations are adopted in hardware design, fabrication procedures and calibration method. Although it has a moving coil suspended by a pair of diaphragm springs, the high-shock durability is attained by reducing movable components to a minimum. Since the penetrators will not be emplaced in the lunar regolith in an exactly vertical attitude, a rotation mechanism is installed to reorient the seismometer to the desired direction. It has already been proved that both the flight-type seismometer and its gimbals mechanism do not show any significant change of their characteristics after penetration into the simulated lunar soil, even under the low temperature condition as expected on the lunar surface. To verify the dynamic characteristics of the LUNAR-A seismometer, a series of field tests to measure natural ground motion (what is called 'microseism') have been conducting at a tunnel of the Inuyama Seismic Observatory in Central Japan, where the amplitude level of microseism is quite low and equivalent to the typical signal level of deep moonquakes (Yamada et al., 2005). In these tests, there are mainly three key points to evaluate our seismometer system. The first is a comparison of sensor performance before and after an impact test; the second is an evaluation of each noise level of the sensor, preamplifier and analog filter as well as of the overall system. The last one is the long-term stability of the sensor and gimbal system for sensing natural ground motion. Concerning the data acquisition, both an L-4 geophone for explosion seismology and an STS-2 broadband seismometer for global seismology were set on a nearby reference base. In the early phase of field tests, the outputs from these three types of reference seismometers through their analog amplifiers are recorded with a high resolution of 24 bit and with over-sampling of 200 Hz. This is because it is convenient to numerically analyze their waveforms and compare them at a broad frequency range. Figure. 1 shows one example of a waveform obtained in a series of tests. For comparison among three types of seismometers, observed waveforms are transformed into each seismometer response function. The maximum amplitude of deep moonquakes in terms of the velocity of ground movement is comparable to $10^{-7}$ to $10^{-8}$ m/sec. No significant difference can be seen among the three seismic waveforms, illustrating achievement of the desired behavior of the LUNAR-A seismometer. In a later phase, observations by the seismometer system onboard a model penetrator have been conducted. As mentioned above, a gimbal mechanism is used to reorient the two-component seismometer to the desired direction after penetration. Therefore, a qualification model of the penetrator, which is almost identical in design to the flight model, is configured for measurements following an impact test, and then the gimbal mechanism is adjusted so that the internal two-component seismometer attains its neutral position (Figure. 2). Using the same telecommunication and data handling system as the LUNAR-A spacecraft, we can simulate the operation so as to make a seismic observation on the Moon. As results of a series of field tests, it has been confirmed that the seismometer offers the required shock durability and works well as designed both before and after impact, and that the gimbal mechanism can maintain the neutral position of the seismometer for three months or longer. We are also studying how to enlarge the bandwidth of the Lunar-A seismometer toward 10-20 sec, in order to detect long period body waves with...
a higher dynamics and resolution. Such waves are expected to be less sensitive to diffraction (and attenuation) than 1 Hz waves. This will be based on an electrical feedback and may provide a sensitivity a couple of tens time higher than that of the present LUNAR-A short-period sensor, in the frequency ranges of 10 to 20 seconds.

Figure 1. Comparison of seismic waveforms for three types of seismometers measured simultaneously; the upper is a waveform for STS-2 broadband seismometer, the middle for L-4 geophone and the lower for LUNAR-A seismometer.

Figure 2. Photograph of a penetrator model of qualification and its supporting equipments set on the tunnel of Inuyama seismic observatory.

REFERENCES


PRINCIPAL AUTHOR’S BIO (~50 WORDS)

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