Characteristics of a seismometer for the LUNAR-A penetrator. Ryuhei Yamada[1,4], Isao Yamada[2], Naoki Kobayashi[3], Nozomu Takeuchi[4], Hiroaki Shiraishi[1],Satoshi Tanaka[1], Akio Fujimura[1], Hitoshi Mizutani [1], and Lunar-A Penetrator Science Team [1]Institute of Space and Astronautical Science (ISAS/JAXA) (Sagamihara, 229-0006) (e-mail address:ryamada@planeta.sci.isas.jaxa.jp), [2]The University of Nagoya (Chikusa-ku, Nagoya, 464-8602) [3]Tokyo Institute of Technology (Ookayama, Meguro-ku, Tokyo, 152-8551) [4] The University of Tokyo (Hongo, Bunkyo-ku, Tokyo, 113-0033)

1. Introduction(seismometer)

A seismometer for the LUNAR-A penetrator[1,2] is developed, and dynamic character of the seismometer is shown in the present paper.

The shape of the seismometer is cylindrical; 50mm in diameter and 50mm in length, and the weight is ca. 350g (Figure 1). The pendulum is composed of a pair of coils suspended by a pair of diaphragm springs. The natural frequency of it is in the range from 1.2Hz to 1.0Hz. Because of small mass of the pendulum compared with the mechanical stiffness of the diaphragm spring, it is difficult to realize such a long natural period in the present size of a seismometer. A pair of small chips of metal attached to the pendulum in a weak magnetic field made by the leak from magnetic circuit is used to lengthen the natural period of the pendulum. The combination of the magnetic force on the small chip of metal and the thin(0.11mm) mechanical diaphragm spring yields an effectively weak spring. The sensitivity is 1080V/(m/sec), which is brought up by an adequately designed magnetic circuit consisting of a REE magnet and a highly permeable core, and the coils wound with 20-micron meter Cu wire more than 30000 turns. One coil is also wound with 7 turns of hevier Cu wire (60-micron meter in diameter) in order to move the pendlum for a calibration by loading current.

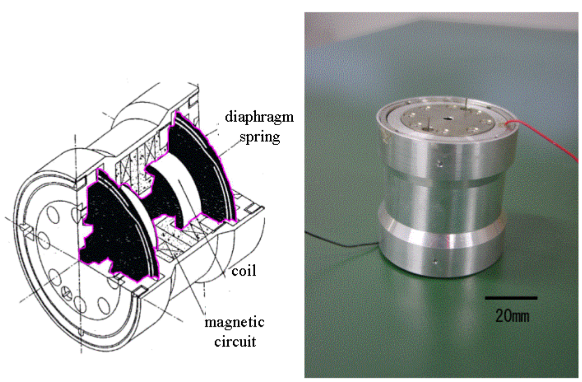

Figure 1. Illustration and photograph of the LUNAR-A seismometer

The seismometer is expected to work its best performance at a low temperature condition of the lunar surface, i.e., -20 to –30 degrees Centigrade, after an impact shock of 8000G when the penetrator impacts on the lunar regolith. In order to verify the designed characteristics, we tested the seismometer in the penetrator with impact tests, which simulate the impacts condition of the penetrator on the lunar surface.

2. Observation of microtremor

After the shock experiment, the dynamic response of the seismometer is measured at the seismic observatory, where the ground noise is extremely low (about 1E-7~1E8 m/sec with velocity of ground movement). Since deep moonquake amplitude level on the lunar surface is also low (about 1E-8~1E-9 m/sec), and the newly developed LUNAR-A seismometer is very sensitive, the dynamic response of the seismometer should be examined under a quiet condition.

The LUNAR-A seismometer is set on the ground base of the Inuyama Seismic Observatory of Nagoya University. The ground motion (microtremor) was observed from December 26 2002 to January 1 2003. In this holiday period, the artificial noise derived from regional social activity is significantly reduced. Observations of the microtremor during the same period were also achieved for comparison by using L-4 geophone and STS-2 seismometer. The L-4 geophone is an electromagnetic type with a pendulum suspended by two diaphragm springs. Its structure is similar to that of the LUNAR-A seismometer, however L-4 is about 3.5 times lager (about 17cm in length) and about 2.5 times heavier (see table1). On the other hand, STS-2 seismometer is employed for reference of the observation of microtremor. These seismometers were set apart from each other within 1.5m. The specifications of these seismometers are listed in table1.

	LUNAR-A	L-4	STS-2
natural frequency(Hz)	1.1 (1.1)	1.0	0.00833
sensitivity (KV/m/sec)	1.08(above 1.0)	0.171	1.5
mass(g)	~350	968.7	13000

Table1. Specification of seismometers
(The value in a parenthesis shows that obtained at –20 degree Centigrade.)

Three types of amplifiers are prepared for the observation, the gain factor of these amplifiers are 1000,750 and 100. The amplifier with 750 gain factor is the same one as the flight model preamplifier for the LUNAR-A mission. In order to observe the microtremor, the amplifier with the 1000 times gains was used for the L-4 geophone, and the amplifier with 100 times gain was used for the STS-2 seismometer. These outputs from the amplifier are connected to the data logger (DATAMARK LS8000WD, Hakusan Co.) and recorded with 24bit and 200 samples per second. In our laboratory, we examined output noises of these amplifiers-data logger system. Considered with these noise levels and gain factor, sensor sensitivity, it is expected to record microtremor above about 3E-9 m/sec. These amplifiers and the data logger are operated by the individual battery power source to prevent the noise from commercial electric power line.

3. Result and Discussion

The observed seismic data are corrected in the amplifier gain factor, sensitivity, and response curves for each seismometer. The power spectrum densities are calculated and compared among the three types of seismometers (Figure.2). The differences among these three data sets do not exceed 20% in the range of 0.2Hz to 6.0Hz (the LUNAR-A seismometer is designed to function under 6Hz). Amplitude of the observed microtremor is similar to a level to typical strong deep moonquakes.

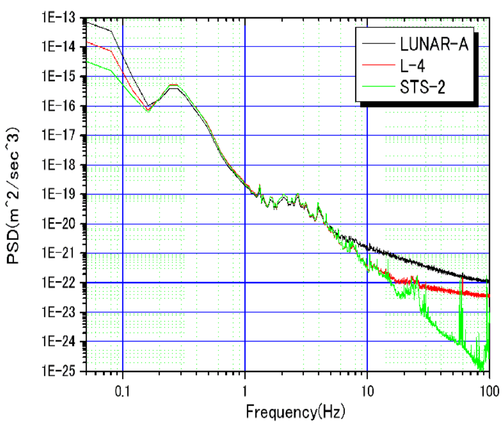

Figure 2. Power spectrum density of ground motions observed by three types of seismometer at Inuyama Seismic Observatory, Nagoya University (Dec.26 2002-Jan.1 2003)

The test of the LUNAR-A seismometer at the seismic observatory was made at room temperature condition, which is not at the same condition as that of the lunar surface. However, we proved that the LUNAR-A seismometer does not show any significant variation of the characteristic under the temperatures from –20 degrees Centigrade to +20 degrees Centigrade after the shock experiment. This fact implies that the seismometer preserves its initial characteristic throughout the shock event and temperature difference (Figure 3).

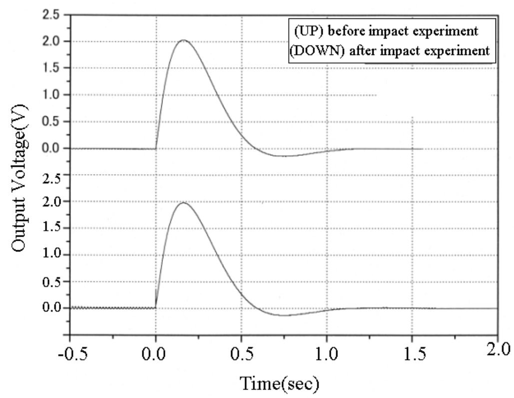

Figure3. Calibration waveforms of the LUNAR-A seismometer at room temperature. The upper and lower curves represent respectively the calibration curves before and after the impact experiment.

These tests of the LUNAR-A seismometer demonstrate that the it will survive the shock loading encountered at the penetrator impact on the lunar surface and it will function as expected to register moonquake events. We are looking forward to using this highly sensitive and very robust seismometer in the forthcoming LUNAR-A mission.

Reference

[1] H. Mizutani, A. Fujimura, M. Hayakawa, S. Tanaka and H. Shiraishi, (2001) in “Penetrometry in the Solar System”, eds N. I. Komle, G. Kargl, A. J. Ball, and R. D. Lorenz, Verlag der Osterreichischen Akademie der Wissenchaften pp125-136

[2] H. Mizutani, A. Fujimura, S. Tanaka, H. Shiraishi, and T. Nakajima, (2003) Advances in Space Research, vol. 31, No.11, pp.2315-2321