Reflector Arrangement on H2A-LRE Satellite

Toshimichi Otsubo (otsubo@crl.go.jp)

Communications Research Laboratory, 893-1 Hirai, Kashima 314-8501 Japan

Hiroo Kunimori

Communications Research Laboratory, 4-2-1 Nukui-kita, Koganei, Tokyo 184-8795 Japan

Keisuke Yoshihara and Hidekazu Hashimoto

National Space Development Agency of Japan, 2-1-1 Sengen, Tsukuba 305-8505 Japan

1. Introduction

The National Space Development Agency of Japan (NASDA) successfully launched its new rocket H-IIA on 29 August 2001. It released a spherical laser ranging target called Laser Ranging Equipment (LRE; Fig. 1), for the assessment of the trajectory of the rocket, into a geosynchronous transfer orbit with an inclination of 28.5 degrees [1-2]. The LRE satellite is unique in that it carries two kinds of reflectors; made of synthetic silica and made of BK7.

Since it was launched, the satellite was optically visual but not able to be tracked by laser ranging for more than three months despite intensive efforts from worldwide laser ranging network. The geosynchronous transfer orbit was so challenging to our community. However, it was 17 December 2001 when the Grasse LLR station (France) obtained the first return from the satellite [3]. Since then, with the improved orbit prediction, it has been tracked from the Grasse LLR station, the Yaragadee station (Australia) and the CRL Koganei 1.5m-telescope station (Japan) [4].

In this paper, the satellite signature effect is discussed for the LRE satellite. Then we present how to monitor the spin rate and the optical degradation of reflectors from the unique arrangement of reflectors. An initial result is also presented.

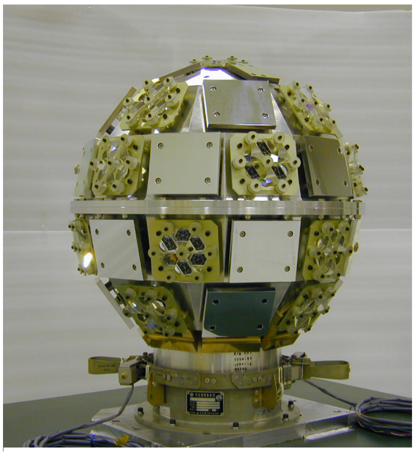

Fig. 1: Laser Ranging Equipment (courtesy of NASDA).

2. Specification of the satellite

LRE carries both curved mirrors and cube corner reflectors. The mirrors with a curvature of 10 m are used for sunlight reflection and passive optical observations. The cube corner reflectors reverse the direction of incident beams and therefore a laser pulse transmitted at a terrestrial station is 'retroreflected' toward the station. The LRE satellite is 0.5 m in diameter and 87 kg of mass. It carries not only synthetic silica reflectors and but BK7 reflectors that are not

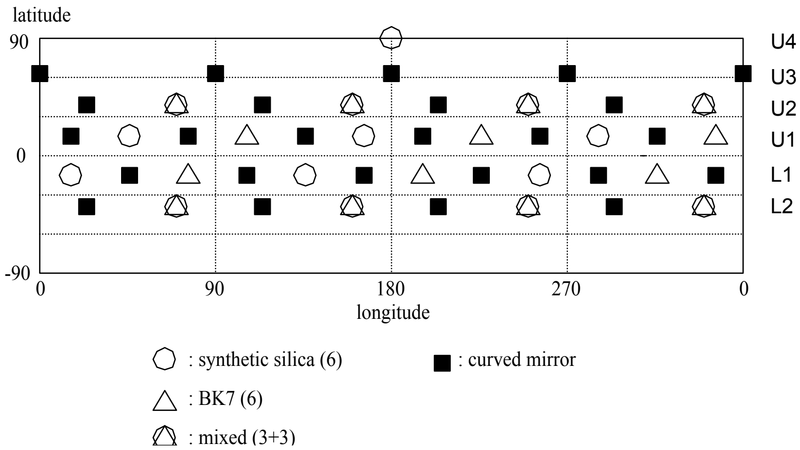

Fig. 2: Arrangement of cube corner reflectors and curved mirrors on LRE.

radiation resistant, and expected to degrade in several months. The main reason we used the BK7 reflectors was the fact that we could not produce sufficient number of synthetic silica reflectors in the limited preparation period. It is nevertheless of interest to monitor the degradation process of the BK7 glass in the radiation environment present along the geosynchronous transfer orbit of LRE.

The LRE satellite is shaped like a quasi-spherical cannon ball, and consists of two hemispheres, an upper and a lower. The upper hemisphere has four rows and the lower has two. The reflector dimensions are common to all the reflectors. The front face is a triangle with the vertex cut and is identical to AJISAI. The index of refraction of synthetic silica is 1.46 and that of BK7 is 1.52 (both for the 532 nm wavelength), although, for the size of the LRE reflector, it causes only a tiny difference of the optical path below 1 mm. 66 reflectors are made of synthetic silica and 60 are made of BK7 glass.

Six reflectors are placed in a single holder. The reflectors are placed in a holder in one of these configurations: six synthetic silica reflectors, six BK7 reflectors, or three of each. We designed the arrangement of reflectors shown in Fig. 2 so that the degradation of BK7 can be monitored from laser ranging data whose analysis process is discussed later.

There are 12 faces per row in the two rows around the equator of the satellite (U1 and L1), 8 faces per row in the second rows from the equator in the both hemispheres (U2 and L2), 4 faces per row in the third row in the upper hemisphere (U3) and 1 face on the top in the upper hemisphere (U4). In the U1 and L1 rows, the reflector holders are placed every other faces and have either all synthetic silica or all BK7 reflectors. As shown in Fig. 2, the same type of reflector holders is mounted every 4 faces, i.e., 120 degrees of longitude. In the U2 and L2 rows, the reflector holders are also mounted every other face, i.e., 90 degrees of longitude, and each of them has three BK7 reflectors and three synthetic silica reflectors. On the top (U4), the holder carries six synthetic silica reflectors.

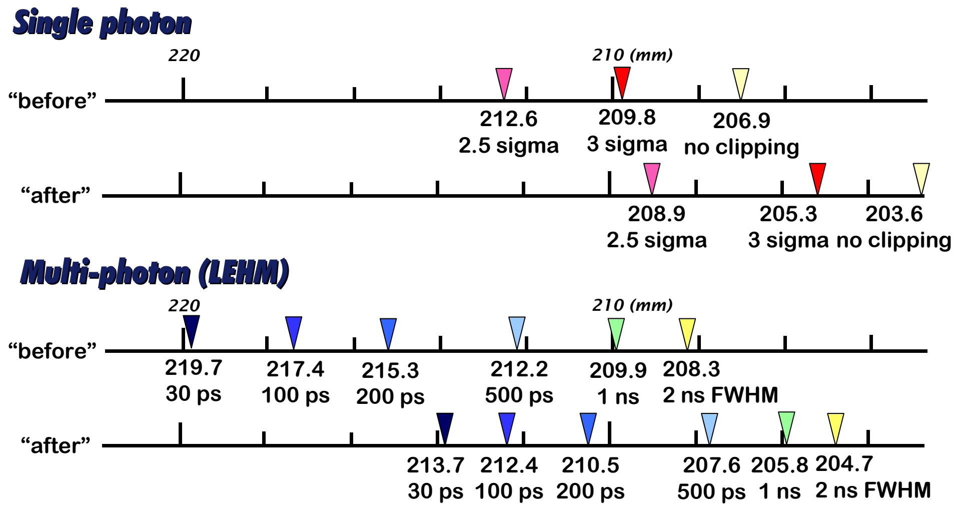

Fig. 3: System-dependent centre-of-mass correction of LRE.

3. Satellite signature effects

When we simulated the optical response of a single reflector of LRE, we could use almost the same model as AJISAI to calculate the effective reflection area, the reflectance, and the optical delay inside a reflector. In this study, we neglected the diffraction effect. That is, the retroreflected intensity was modeled to be proportional to the effective reflection area and the reflectance. Due to the sparse distribution of reflectors, the retroreflected pulse shape changes with respect to the angle of incidence toward the satellite. We numerically produced the retroreflected pulse for each of 10267 angles of incidence with a two-dimensional interval of about two degrees.

Assuming a very narrow pulse (width: 1 ps full width at half maximum (FWHM)) of incidence, we constructed the target response function that is the sum of the shapes from all the angles before and after the degradation of the BK7 reflectors. Following the algorithm applied to other spherical satellites [5][6], we calculated the centre-of-mass correction for typical laser ranging systems. The centroids of the response functions before and after the BK7 degradation, 207 mm and 204 mm respectively, correspond to the mean of the centre-of-mass correction for ideal single-photon ranging stations, but in reality the data in the tail is rejected as noise data when generating the normal point data. When we assumed iterative 3-sigma rejection, we got larger centre-of-mass corrections at 210 mm and 205 mm. For a tighter criterion of iterative 2.5-sigma rejection, they were slightly larger, 213 mm and 209 mm (Fig. 3).

Using the above-mentioned retroreflected pulse shapes simulated for 10267 angles of incidence, we also calculated the centre-of-mass corrections for multiphoton detection systems.

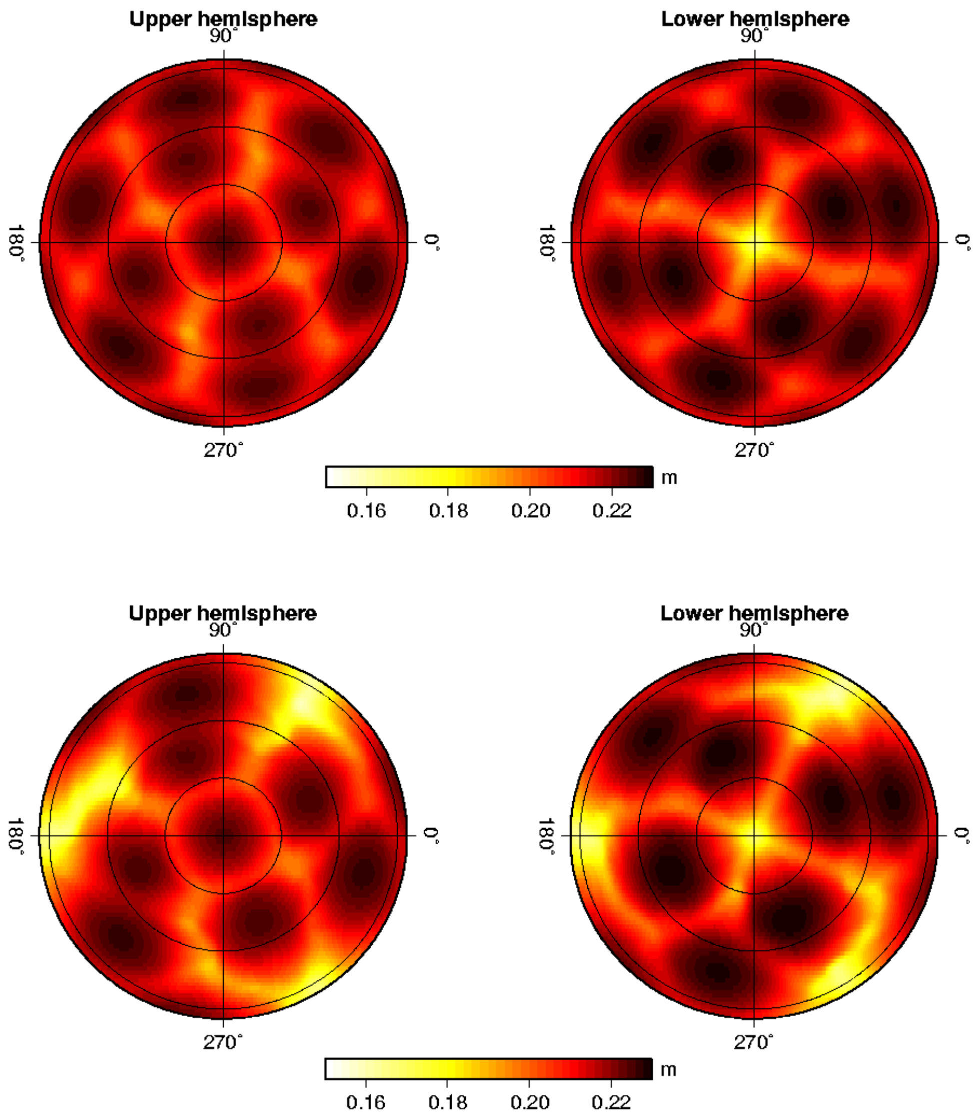

Fig. 4: .Directional variation of the centre-of-mass correction for a 200-ps LEHM system before (top) and after (bottom) the degradation of the BK7 reflectors.

We assumed a gaussian noise only in the transmitted laser pulse and took the half maximum point in the leading edge as the detection time. For the system whose laser pulse width is 200 ps FWHM, the two-dimensional variation of the centre-of-mass correction is illustrated in Fig. 4 for the case before the BK7 degradation and for the case after the BK7 degradation. Due to the sparse distribution of reflectors, the directional variation, 2 to 5 cm peak-to-peak, is much larger than that of the slightly larger LAGEOS satellites[6] on which the reflectors are densely placed.

The change of patterns from Fig. 4 (top) to Fig. 4 (bottom) is the key to the detection of the degradation of BK7 reflectors, as discussed in the following section. If all holders had three

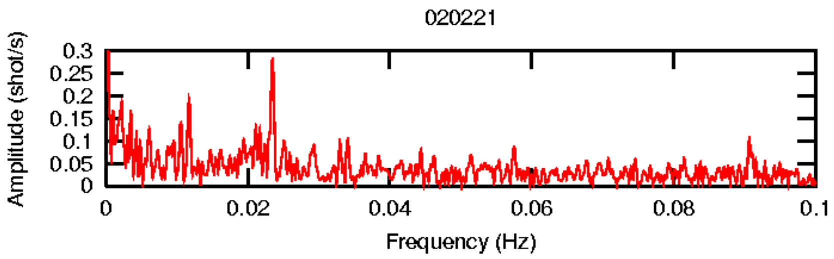

Fig. 5: The spectrum of the return rate (returns per second) of a pass observed on 21 Feb 2002 at the Grasse LLR station.

synthetic silica reflectors and three BK7 reflectors, there would be no such change of pattern. Fig. 3 shows the centre-of-mass corrections before and after the BK7 degradation for several multiphoton systems having different laser pulse widths. Note that the actual signal processing performed in laser ranging systems is much more complicated, and that this simplified model will give just approximate values of centre-of-mass corrections.

If one needs 1-cm accuracy in orbit analysis, the centre-of-mass correction of 210 mm will satisfy all cases. For more precise analysis, one should consider system-dependent values.

4. Detection of spin rate and BK7 degradation

Like the rotation of the Earth, the spin of a satellite is stabilized at the axis around which the moment of inertia is maximized. For LRE, the spin axis should be the pole of the upper and lower hemispheres, i.e., the centre of the polar coordinates in Fig. 4.

Assuming that a laser ranging station can keep tracking a fast spinning satellite, the direction of incidence moves 360 degrees in longitude per rotation whereas it moves little in latitude. We can read from Figs. 5 and 6 that the observed range should have periodical variation. Through spectral analysis of the full-rate range data, it was reported that the spin rates of AJISAI and LAGEOS-2 were successfully derived by the spectral analysis for unevenly spaced data [7][8]. We assume the same analysis strategy in this study. In Fig. 4 (top), i.e., while both types of reflectors remain active, the obvious patterns are either every 60 degrees around the satellite's equator or every 90 degrees at mid-latitude. The cyclic signal in the observed range will therefore emerge at the sixth and fourth harmonics of the fundamental spin rate. On the other hand, after the BK7 reflectors are degraded, as seen in Fig. 4 (bottom), the patterns changes around the equator; they are either every 120 degrees or 90 degrees. The cyclic signal will be at the third and fourth harmonics of the fundamental frequency.

The intensity of the return pulse is also modeled to vary in a similar way as the range measurement. When the larger centre-of-mass correction is expected (i.e. the range is measured shorter), the return intensity should be strong. The cyclic signal is also expected in the intensity (such as the direct intensity measurement and the return rate).

At this moment, the data analysis has not been very successful – the spectral analysis cannot extract a clear peak in the frequency domain. One of the best results is shown in Fig. 5. We used here the return rate (the number of returns per second) of a pass observed on 21 February 2002 from Grasse, instead of the post-fit range residuals with which the peak was not as clear. The peak in Fig. 5 is located at 0.0235 Hz (1/42.55 sec). On the same day, the video image of the glints was observed by an ICCD camera at CRL Koganei station. The intervals between the adjacent glints were around 85 seconds, which is very close to the half frequency as the above result. With these facts, the spin period cannot be identified but must be related to the two numbers.

5. Conclusions

The LRE is the first satellite that was intended to monitor spin rate by laser ranging observation from the design phase. It carries reflectors made of BK7 glass that will degrade in several months. We designed a non-uniform arrangement of BK7 reflectors and synthetic silica reflectors to observe the degradation process of its BK7 reflectors as well as the spin rate of the satellite. We detected some signals obviously related to the spin period, but have not yet identify it.

References

[1] T. Otsubo, H. Kunimori, K. Yoshihara and H. Hashimoto, "Optical response of the H2A-LRE satellite," SPIE Proceedings Series 4546, 44-48, 2001.

[2] T. Otsubo, H. Kunimori, K. Yoshihara and H. Hashimoto, "Laser reflector arrangement on H2A-LRE satellite for monitoring spin period and optical degradation," Applied Optics, 41, 27, 5672-5677, 2002.

[3] J.-M. Torre, "Tracking of the LRE satellite at Grasse with the lunar laser ranging station – difficulties, results and prospect for the future," Proc. Of CRL International Symposium on Light Propagation and Sensing Technologies for Future Applications, 105-106, 2002.

[4] H. Kunimori, S. Oya and Y. Nakamura, "Optical tracking and ranging to a satellite in GTO by 1.5m telescope," Proc. Of CRL International Symposium on Light Propagation and Sensing Technologies for Future Applications, 97-98, 2002.

[5] T. Otsubo and G. M. Appleby, "Recovery of target response function for centre-of-mass correction of spherical satellites," in these proceedings.

[6] T. Otsubo and G. M. Appleby, "System-dependent centre-of-mass correction for spherical geodetic satellites," submitted to J. Geophy. Res., 2002.

[7] T. Otsubo, J. Amagai, H. Kunimori and M. Elphick, “Spin motion of the AJISAI satellite derived from spectral analysis of laser ranging data,” IEEE Trans. Geosci. Remote Sens., 38, 3, 1417-1424, 2000.

[8] G. Bianco, M. Cherisich, R. Devoti, V. Luceri and M. Selden, “Measurement of LAGEOS-2 rotation by satellite laser ranging observations,” Geophy. Res. Lett., 28, 2113-2116, 2001.