**Preliminary results of the laser ranging space experiment of spacecraft «Lomonosov»**

A.S Akentyev, A.L. Sokolov, M.A. Sadovnikov, V.D. Shargorodskiy

Compact retroreflector array (RA) “Pyramid” developed in JSC “Research-and-production Corporation “Precision systems and instruments” represent the pyramid shape construction of four corner reflectors (CRs) with common vertex (Fig. 1). Its mass is about 60 g and overall dimensions do not exceed 40 mm.

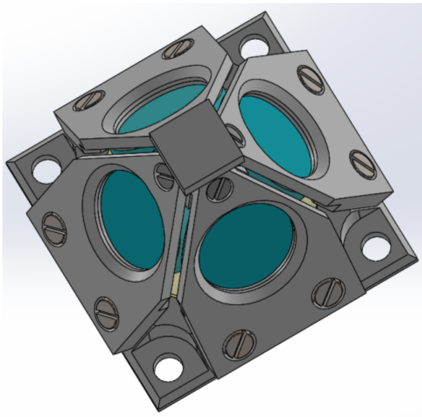

Fig. 1 – Compact retroreflector array “Pyramid”

As it known the value of velocity aberration for low orbit satellites varies from 5" to 12" [1, 2, 3]. It means that at such angle from the axis the CS must be maximal, and it is required to expand the FFDP, for example, to reduce the size of CR. At the same time the aperture decreases, and detected energy of laser radiation reduce.

The goal of design RA with CRs consist from the choice of numbers, optical and geometrical characteristics of CRs with due consideration of them placement for the achievement maximal energy value of detection signal with minimal value of “target error”. The design feature of RA “Pyramid” is the compact placement and the special size of CR in RA (Fig.1).

During the movement of satellite from horizon to zenith, the CR aperture decreases. At zenith area of spacecraft overflying the angle of incident on all four CRs is equal to 54º and the CR aperture approximately equal zero. As the result, CS is maximal at the viewing angle $\theta_z$ = 63º (See fig. 2) and the minimal in case of satellite location at zenith area $\theta_z$ = 0…10º. Maximal values of CS (fig. 2) are reached when the radiation is incident only on one CR. Minimums I correspond to the case when the laser radiation is incident on two CRs during the satellite overflying along the trajectory. Minimums II correspond to the satellite location on traverse. It corresponds to the case of the maximal deflection of axis of reflected laser beam due to the phenomenon of velocity aberration.

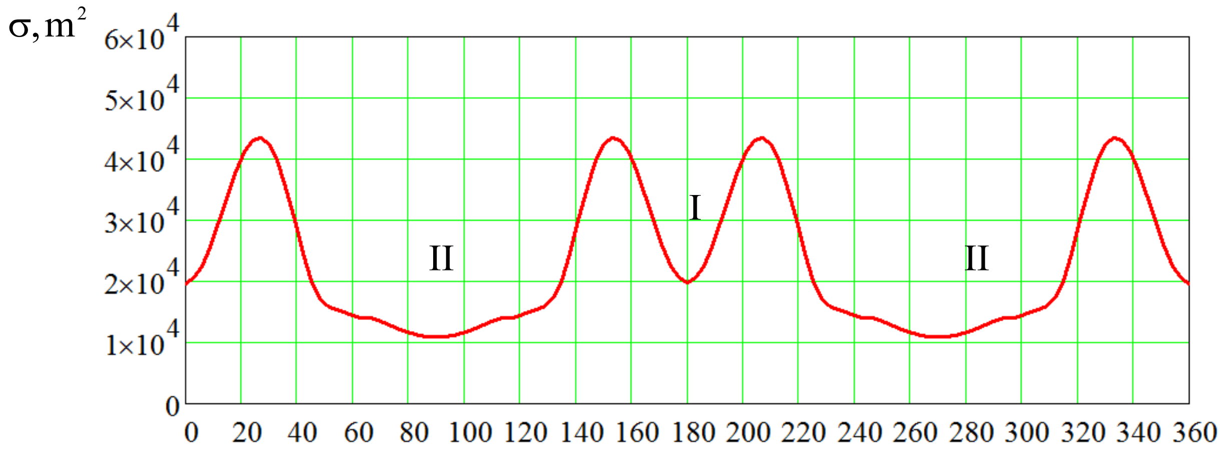


Fig.2 – The dependence of CS from the angle *A* in case of satellite position with zenith angle $\theta_z$ = 63º for the height orbit 500 km: *A* – azimuth angle counting from the plane α

At the same time, the distance to the satellite is minimal in zenith area and maximal (by more than three times) in case of satellite location about horizon line. Since the number of photons reflected from the satellite and received by ground station is inversely proportional to the fourth degree of distance to the satellite, the reduction of CRs aperture in zenith area is compensated by the distance decrease. The results of influence of two factors leads to the fact, that the number of photons recorder by optical and laser station is maximal at zenith viewing angle of satellite $\theta_z$ = 40º. As opposed to the other analogous RAs [4], the quantity of photons reflected from RA “Pyramid” and recorded by photodetector does not significantly vary during the satellite overflying along celestial sphere.

If the distance from laser transmitter to individual CR in RS differs, the extension of response signal causing target error occurs. For RS "Pyramid" the target error is very low at the expense of CR small size and connection of their vertexes. Maximal value of error occurs when the radiation is incident on several CR at once upon their unsymmetrical arrangement from the axis of laser beam, and in such case the optical path in these CR does not concur. Error minimum corresponds to the case of laser beam incidence on two identically oriented CR or to the case of reflection of laser radiation only from one CR. In general, the estimated value of target error does not exceed 0.5 mm when measuring the distance to SC.

Two compact RAs "Pyramid" designed at *JSC "RPC "PSI"* were placed onboard the SC "Lomonosov" within the framework of satellite laser ranging space experiment (Fig. 3). The satellite was launched at sun-synchronous orbit the height of 500 km in April 2016 with the scientific equipment of Moscow State University in order to study the phenomena in the upper layers of Earth's atmosphere.

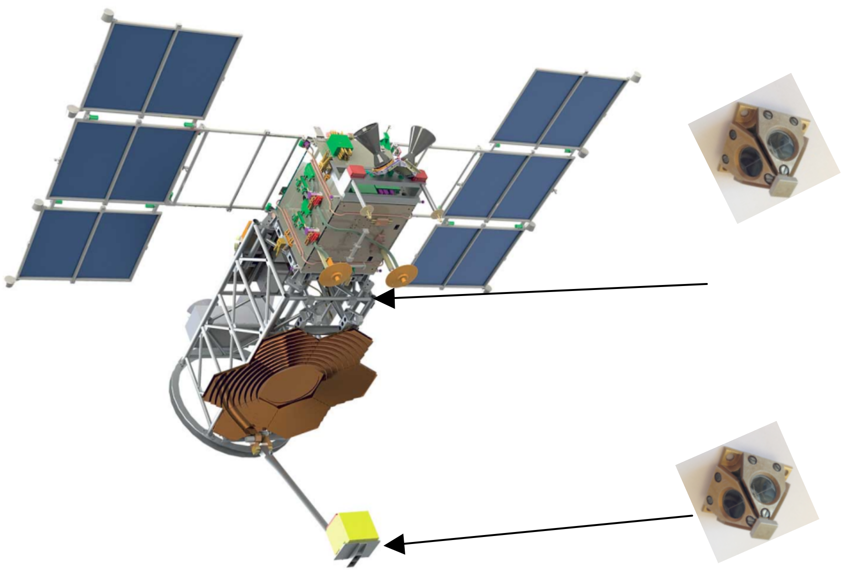

Fig. 3 – SC “Lomonosov” (the RAs are shown in scaled up form)

Table 1 represent the sessions of laser ranging SC «Lomonosov». Carried out laser measurements of distance allowed observing two signal tracks with the distance between them only 0.5-2 m, which depend from the satellite orientation relative to laser station at the moment of observation. In this case, single-photon mode was used. Notwithstanding the small size, every RS provided the sufficient level of response signal. According to our evaluation (the comparative measurements by satellites "Stella" and “Lageos” were performed), CS was up to $5 \cdot 10^4$ $m^2$.

Table 1. – List of stations participates in ranging of SC «Lomonosov»

| Station | Station number | Time of measurement (UTC) | | | | Number of registered pulse | Elevation angle, degrees begin/ parameter/ end. |
|---|---|---|---|---|---|---|---|
| | | mm.dd.yy | Begin | Parameter | End | | |
| Mendeleevo 2 | 1874 | 06.30.16 | 21:28:25 | - | 21:32:03 | 134 | 34,57/-/48,81 |
| Altay | 1879 | 07.06.16 | 18:48:55 | - | 18:50:42 | 1446 | 20,29/-/39,73 |
| Arkhyz | 1886 | 07.06.16 | 20:24:46 | - | 20:27:39 | 2 255 | 11,99/-/ 38,12 |
| Mendeleevo 2 | 1874 | 07.08.16 | 21:05:41 | - | 21:06:40 | 683 | 41,45/-/45,03 |
| Katzively | 1893 | 07.08.16 | 21:06:37 | - | 31:07:46 | 134 | 26,57/-/46,98 |
| Katzively | 1893 | 07.11.16 | 21:20:50 | - | 21:21:29 | 21 | 34,17/-/52,1 |
| Katzively | 1893 | 07.14.16 | 21:33:58 | - | 21:35:47 | 64 | 21,46/-/59,00 |
| Irkutsk | 1891 | 07.20.16 | 17:17:19 | 17:20:05 | 17:20:57 | 240 | 22,12/45,34/25,62 |
| Altay | 1879 | 07.21.16 | 18:27:37 | - | 18:28:56 | 578 | 29,19/-/66,16 |
| Mendeleevo 2 | 1874 | 07.21.16 | 21:34:54 | - | 21:36:25 | 245 | 61,88/-/24,39 |
| Arkhyz | 1886 | 07.24.16 | 20:16:28 | 20:17:15 | 20:18:36 | 916 | 22,37/29,51/26,83 |
| Mendeleevo 2 | 1874 | 08.09.16 | 23:55:36 | 23:56:52 | 21:58:32 | 2 627 | 24,80/44,80/31,69 |
| Svetloe | 1888 | 09.13.16 | 22:31:27 | 22:32:02 | 22:35:16 | 392 | 24,91/48,07/20,53 |
| Yarragadee | 7090 | 16.10.16 | 03:59:54 | - | 04:00:57 | 40 | 25,07/-/15,00 |
| Yarragadee | 7090 | 21.10.16 | 03:15:55 | 03:16:15 | 03:20:14 | 485 | 19,73/33,12/14,93 |
| Monument Peak | 7110 | 25.10.16 | 19:02:22 | - | 19:03:37 | 80 | 17,34/-/26,35 |
| Yarragadee | 7090 | 30.10.16 | 03:55:46 | 03:56:10 | 03:59:20 | 468 | 35,46/54,19/17,89 |
| Graz | 7839 | 10.11.16 | 08:41:12 | - | 08:50:00 | 1 603 | 18,60/-/10,64 |
| Graz | 7839 | 10.11.16 | 10:14:12 | 10:16:51 | 10:23:24 | 1 348 | 16,35/26,09/15,53 |
| Hartebeesthoek | 7501 | 17.11.16 | 20:24:47 | - | 20:26:05 | 66 | 14,32/-/19,38 |
| Graz | 7839 | 30.11.16 | 09:03:48 | - | 09:14:12 | 814 | 18,88/-/10,10 |
| Yarragadee | 7090 | 04.12.16 | 03:50:05 | - | 03:53:48 | 389 | 15,44/-/19,71 |
| Graz | 7839 | 07.12.16 | 09:02:24 | - | 09:12:48 | 9 221 | 37,63/-/10,29 |

The results of space experiment allow to recommend the retroreflector array "Pyramid" for the mounting to LEO spacecrafts in order to determine their orientation and monitor additionally the deployment of SC components in space.

## References

1. M.A. Sadovnikov, A.L. Sokolov, “Spatial Polarization structure of radiation formed by a retroreflector with nonmetallized faces”, Optics and Spectroscopy, 2009, Vol. 107, No. 2, pp. 201–206.

2. A.L. Sokolov, V.V. Murashkin, A.S. Akent’ev, E.A. Karaseva. “Corner reflectors with interference dielectric coating”. Quantum Electronics, 2013 Vol. 43, p. 795-799.

3. A.L. Sokolov, “Formation of polarization symmetrical beams using cube-corner retflectors, J. Opt. Soc. Am. A, 2013, vol. 30, № 7, p. 1350-1357.

4. Reinhart Neubert, Ludwig Grunwaldt, Jakob Neubert, «The Retro-Reflector for CHAMP Satellite: Final Design and Realization», internet access: http://ilrs.gsfc.nasa.gov/docs/rra_champ.pdf.