Design of Light-weight Laser Retro-reflector for Nano-Satellite

Li Pu (1), Cheng Zhien (1,2), Zhang Haifeng (1), Tang Kai (1),

Zhang Zhongping (1), Li Xie (3), Tang Geshi (3)

(1)Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai
(2)University of Chinese Academy Sciences, Beijing
(3)Beijing Aerospace Control Center, Beijing
pulee@shao.ac.cn

Abstract. *Nano satellites with the characteristics of light weight, compact, short period of manufacture, low power consumption and the high dense functions have been paid more attentions and have the technical advantages in the field of space scientific experiment platform, satellite communication, optical photogrammetry and atmospheric detection. According to the application requirements of nano-satellites used for atmosphere density detection, the light-weight octahedral laser retro-reflector without any power consumption has been designed with the weight of less than 120g, the effective reflecting area of more than 1cm^2, the size of Φ96×20mm for performing laser ranging and providing the indispensable supports of high precise orbit measurement for scientific researches and applications.*

1. Introduction

Nano satellite usually refers to small size, light weight, with the actual use of the function of satellites, which are based on technology of microelectronics, MEMS, micro-optical and other ttechnical development, satellite integrated design and high integration, reflect spacecraft miniaturization trends. With the development of satellite technology and related new technology, satellite for its light quality, small size, short development cycle, low cost, high intensity and the function etc widely attention.

China‘s first nano satellite for atmospheric detection was developed by the Aerospace Ltd. Dongfanghong satellite, with the weighing 15kg, dimensions 392mm × 392mm × 388mm, will be equipped with dual-band multi-mode GNSS receivers, S / X VLBI transmitter, atmospheric density detectors, laser reflectors and other load. The initial orbit height is 530km and working orbit height is 450km and under the effect of atmospheric drag, the height of orbit is gradually degenerated for atmospheric density detection at different heights.

Nano-satellite precision orbit determination is the foundation to achieve its scientific objectives. For LEO satellites, typically using a variety of international satellite GNSS, DORIS, VLBI, SLR and other measuring technology. Because of the size of nano satellite and power constraints, a small chip level GNSS receiver is used as the major way of satellite orbit determination. Taking into account the small GNSS receiver to determine the phase center accuracy is not high, it is difficult to achieve decimeter level orbit determination capability. For this, the satellite is equipped by the non-power laser reflectors for the global precision laser ranging, as an important high-precision orbit determination techniques.

According to the characteristics of nano satellite and the foundation of laser reflector design for low-orbit satellites Shanghai Astronomical Observatory design the compact reflector for a nano satellite to meet the application requirements of light weight and small size and it is applied to the high-precision satellite laser ranging. This article describes the design of the laser reflector, and the performances of SLR for nano satellite are also analyzed.

2. Nano satellite laser reflector design

2.1 Design requirements

With the characteristics of small size, light weight for nano satellites, the requirements of laser reflector structure, weight of cube corner is set forth. The requirements of installation envelope size is (Φ96mm ± 0.2mm) × (20mm ± 0.2mm), the weight requirements of less than 120g. To achieve different height levels of atmospheric density probe, the orbit height is natural decline in the effect of atmospheric drag without the initiative to adjust after the completion of the satellite in orbit testing tasks. It requires the large field of view for laser reflector to maintain good reflection, and compensates for different orbit height of velocity aberration in order to ensure ground stations to receive laser echo.

2.2 Opt-mechanical Design

(1) Optical Design

a) Single cube corner design

Fused silica glass material is common optical material for current laser reflectors design, which has a good adaptability to the space environment. For nano satellites, consider laser reflector weight and size limits,a single corner reflector with the inscribed circle cutting is used with the aperture of 13.6mm, roof height 10mm.

b) Corner reflector coating design

From the theory of geometrical optics, the light in the reflecting surface is not coated fused quartz corner reflector are generated within the total reflection the largest Angle of incidence of i_c, according to the laws of optics and geometric relations:

$$i_c = \sin^{-1}\left[n\sin\left(\tan^{-1}(\sqrt{2}) - \sin^{-1}\frac{1}{n}\right)\right]$$

Where, n is the refractive index of the optical material cube corner, for fused silica material, refractive index n = 1.455, the acceptance angle is 16.6 °. Figure 1 shows the measured cube reflector optical reflectance with the angle of incidence, where the solid line is the incident surface AR-coated, right-angle corner reflector silver film reflector optical reflectance, dashed for the corner reflector incident no AR-coated surface, rectangular optical reflectance when the reflective surface is not coated. It can be seen, for the right angle corner reflector when the reflecting surface is not coated, when the incident angle is greater than 16.6 degree, a sharp decline in their optical reflectivity. For sodium satellite, in its orbit, the laser beam to the incident angle of the corner reflector will appear larger than 16.6 degree. It is indicated that the right angle reflective face of laser reflector should be coated, in order to avoid full reflectance critical angle decline caused problems.

c) Velocity aberration Compensation Design

For nano satellite, the initial orbit height is 530km and working orbit altitude is 450km. Under the effect of atmospheric drag, the final 300km orbit can be reduced and its maximum velocity aberration is about 10.5“-10.8”. To ensure satisfied satellite ground station may measure the received echo signal when at different orbital altitude, we will dihedral corner reflectors designed to offset about 1.5 "dihedral angle deviation, so the reflector far field spot to meet the speed of light row poor demand compensation. As shown in Figure 2. As can be seen from the figure, the angular diameter is about 33” with certain intensity and can meet the needs of velocity aberration compensation of nano satellite .

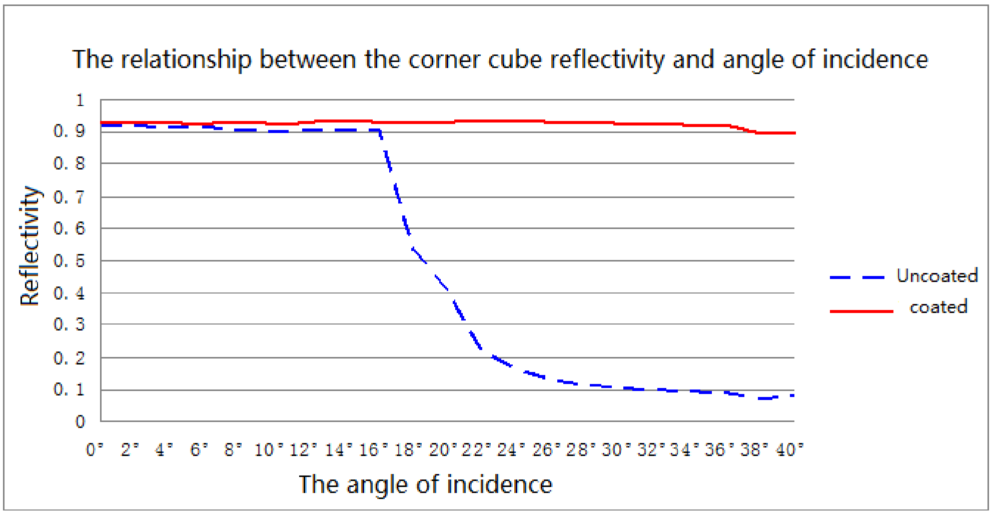

Figure 1. The relation of optical reflectivity to incidence angle for coated and uncoated cube corner

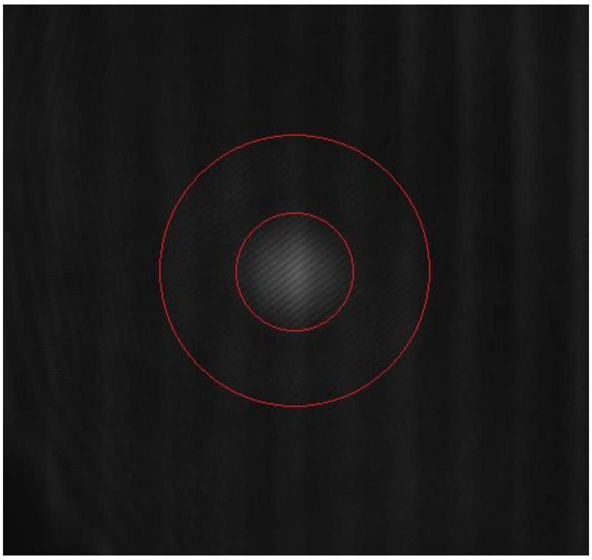

Figure 2. Distribution of Far Field Diffracted Patter for a single cube corner

(2)Mechanical Design

Principle of laser reflector array design is to make the reflector relative to the observed elevation station at 20 degree to 85 degree, it can guarantee effective reflection area. By task analysis for laser reflector and considering the weight, dimensions limits, the number of 12 cube corners with the aperture of 13.6mm is designed consisting of an octagonal table reflector array shown in Figure 3, where 4 corners is installed in the symmetrical octagonal table in the bottom surface, and the remaining eight ones are evenly distributed in eight octagonal table side, whose normal octagonal table with the bottom surface normals angle was 50 degree angle. The diameter of installed base for laser reflector arrays is 96mm, height 20mm, chassis weight about 55g and the array structure centroid distance between the bottom mounting surface distance is 9.7mm. In order to adapt to dramatic changes in the ambient temperature of the space, a single corner reflector mounted in a separate circular aluminum mirror base, with a protective circle around to ensure the stability of a single corner reflector, not due to temperature changes caused by fragmentation.Single corner reflector outer edge caliber 15cm, weight about 5g, the total weight of about 115g.

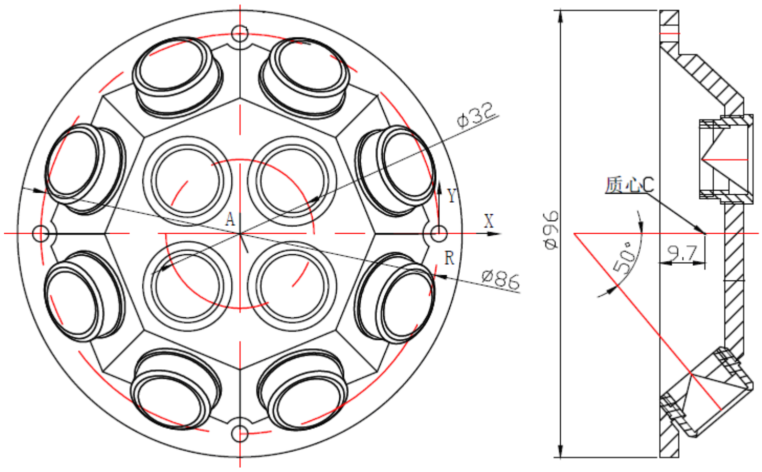

Figure 3. The structure design of laser retro-reflector for nano-satellite

2.3Simulation of the effective reflection area

(1)Single corner reflector effective reflection area calculation

For the inscribed circle cut mining individual corner reflectors, clear aperture is D, the reflection area $\left(\frac{D}{2}\right)^2$, considering the corner reflector optical reflectance ρ , the effective reflection area becomes $\pi\left(\frac{D}{2}\right)^2\times\rho$, the result is a laser at normal incidence. In the laser incident angle of , the need to consider the relative area of the effective reflection coefficient $\eta(i)$:

$$\begin{cases} \eta(i)=\dfrac{2}{\pi}\left(\sin^{-1}\mu-\sqrt{2}\mu\tan\phi_{ref}\right)\cos i \\ \phi_{ref}=\sin^{-1}\left(\dfrac{\sin i}{n}\right) \\ \mu=\sqrt{1-2\left(\tan\phi_{ref}\right)^2} \end{cases}$$

Where η is the relative effective reflection area (in the range of 0 ~ 1), is the refractive index of the corner reflector material (fused silica, n = 1.455), then a single corner reflector effective reflection area and the laser incident angle, Aperture the optical reflectivity relation to $\pi\left(\frac{D}{2}\right)^2 \times \rho \times \eta(i)$.

(2)Laser reflector array computing the effective reflection area

For laser reflector array effective reflection area, just get a laser beam relative to each corner reflector array of the angle of incidence, using a single corner reflector effective reflection area calculation formula to calculate the respective corner reflector effective reflection area $A_j(j = 1,2,\cdots N)$, the laser reflector array reflecting the total effective area

$$A = \sum_{j=1}^{N} A_j = \pi\left(\frac{D}{2}\right)^2 \times \rho \times \sum_{j=1}^{N} \eta_j(i)$$

Figure 5 shows a single laser reflector relative reflection area taking the laser reflector array 100 is relatively effective reflection area map, a broken line in FIG concentric series represents the incident angle of the contour line (0 ~ 90 °, the dotted line interval is 20 °), the peripheral spacer 30 degree angle indicates the azimuth φ (0 ~ 360 °), which coincides with the x-axis when φ= 0 °.

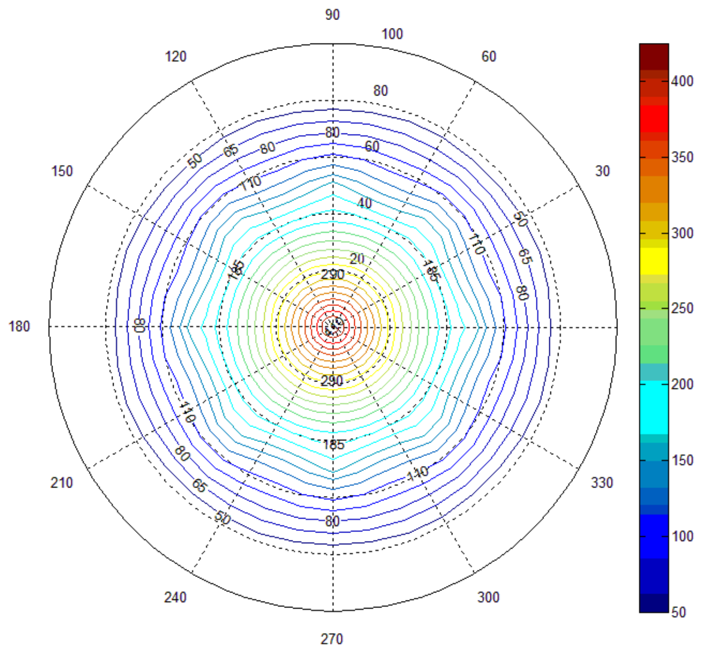

Figure 5. The distribution of the relative effective reflecting area of nano-satellites laser retro-reflector

For the nano satellite laser reflector, the aperture of single corner D = 13.6mm, the incident plane geometry area 1.45cm^2, consider a single corner reflector optical reflectance of 88% @ 532nm, the single angle perpendicular to the incident laser reflectors effective reflection area of 1.45 * 0.88 = 1.27cm^2. According to the calculation results:

I. When the vertical incident light beam, namely 0 ° Angle of incidence, the effective reflection area is 1.27 cm^2

II. When the beam incidence angle θ is 40 °, the effective reflection area of minimum 2.34cm^2

III. When the beam incidence angle θ is 60 °, the effective reflection area of minimum 1.33cm^2

IV. When the beam incidence angle θ is 67 °, the effective reflection area of minimum 1.05cm^2

According to the work, the satellite orbit height, the ground observation lowest elevation take 20 degree, corresponding to the laser incident angle about 67 degree. By the simulation calculation shows that within the scope of laser beam incident angle of 0 ~ 67 degree, the laser reflector effective reflection area is not less than 1.05 cm^2.

4. Summary

For LEO satellites, the high precision satellite laser ranging has become the important measuring techniques during the process of scientific research and is widely used in the field of laser geodynamics satellites, ocean observation, physiognomy mapping. Nano satellites with the characteristics of light weight, compact, short period of manufacture, low power consumption and the high dense functions have been paid more attentions. For the first nano satellite for atmosphere density detection, the requirement of precise orbit determination should be realized by using the different measuring techniques. Among of them, laser ranging is regarded to be the indispensabe observation.

According to the application requirements of nano-satellites used for atmosphere density detection, the light-weight octahedral laser retro-reflector without any power consumption has been designed with the weight of less than 120g, the effective reflecting area of more than 1cm^2 and the size of Φ96×20mm for performing the laser ranging and providing the indispensable supports of high precise orbit measurement for scientific researches and applications.

Reference:

Jin Zhonghe,Jin Xiaojun. Development and Applications of pico- and nano satellites, workshop of small satellites, 2011,1-8

Zhao Weiyu, Bai Baocun, Jin Zhonghe. Application of pico-and nano-satellites and analysis of characteristics, space international, 2013.8

ILRS. International Laser Ranging Service. [2015-09-03]. http://ilrs.gsfc.nasa.gov/missions /satellites_missions/future_missions/PN-1.html