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## The design of laser retro-reflectors for the onboard lidar and its application in the docking mission of Chinese Tiangong-1 space lab module

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**Abstract:** *In the first Chinese spacecraft docking mission of Tiangong-1 space lab module, the onboard lidar technology was adopted for searching and precisely measuring the distance between the involved two docking spacecrafts. Shanghai Observatory has designed and developed laser retro-reflector for the onboard lidar system. The laser retro-reflector was installed on the surface of Tiangong-1 space lab module to reflect the laser signal from the Shenzhou spacecraft which can obtain the azimuth, elevation and distance of Tiangong-1 spacecraft. To meet the requirements of the onboard lidar measuring system, the laser retro-reflector needs to achieve the characteristics of larger reflective area, large field of view and light weight. The reflectors consist of two kind components, the far field cooperative object and the near field cooperative object. The former is assembled with multi sets of different dimension corner cube arrays to make its field of view up to  $90^{\circ} \times 105^{\circ}$  and the minimum reflective area over  $100\text{cm}^2$  at the distance of more than  $20\text{km}$  for the purpose of searching object. The later one is the single large corner cube called near cooperative object for the high precise distance measurement when the range of two spacecrafts is near. This paper introduces the design of laser retro-reflectors for the onboard lidar and its application in the Chinese docking mission.*

### 1. Introduction

The spacecrafts docking mission is one kind of the orbital maneuver within two spacecrafts. One is a space station at the orbit and the other one reaches and approach to close distance and connect each other to make a big body.

During the process of spacecrafts docking, the distance between two spacecrafts accurately measured is one of the key steps. The lidar is a method of detecting distant objects and determining their position, distance, velocity by measuring pulsed laser light reflected from the objects with characteristics of narrow beam, high resolution, small size, light weight and high accuracy. The lidar system is made up of laser transmitter, receiver and retro-reflector. Fig.1 shows principle of lidar system. The laser retro-reflector with the ability to rebound laser pulse signal emitted from laser transmitter is one of the key equipments with light weight and large field of view (FOV). In the first TG-1 docking mission in China, the onboard lidar measuring system is adopted for accurately measuring to distances between spacecrafts. The laser retro-reflector is installed on the docking surface of TG-1 spacecraft.

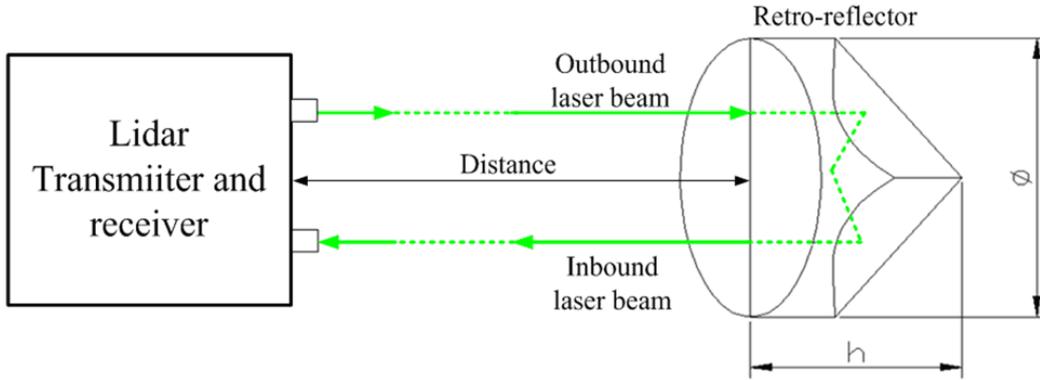


Fig.1 The principle of lidar measuring system

## 2. Design of Laser retro-reflector for onboard lidar

For meeting the requirements of applications of onboard lidar in the docking mission of TG-1 spacecrafts, two kinds of components for laser retro-reflectors are designed, achieving the purpose of far field search ( $\sim 20\text{km}$ ) and the near field ( $< 100\text{m}$ ) accurate measurement respectively. The one for far field search should have the characteristics of larger reflective area, large field of view. So the laser retro-reflector assembled with 8 sets of different dimension arrays (Fig.2 (A)) with a total of 86 corner cubes made of fused silica by way of triangle incision has been adopted. The angle between the normal of array1 and array2 is 56 deg, the angle of array2 and array3 is 20 deg and the angle of array2 and array3 is 40 deg. The single large corner cube (Fig.2 (B)) by the way of triangle incision for near field is used.

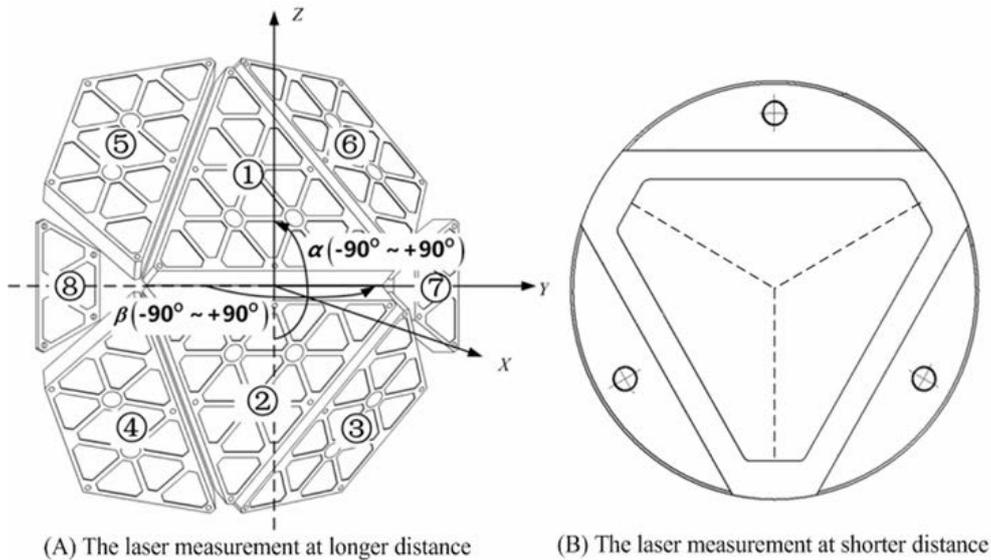


Fig.2 The structure of laser retro-reflector in lidar measuring system

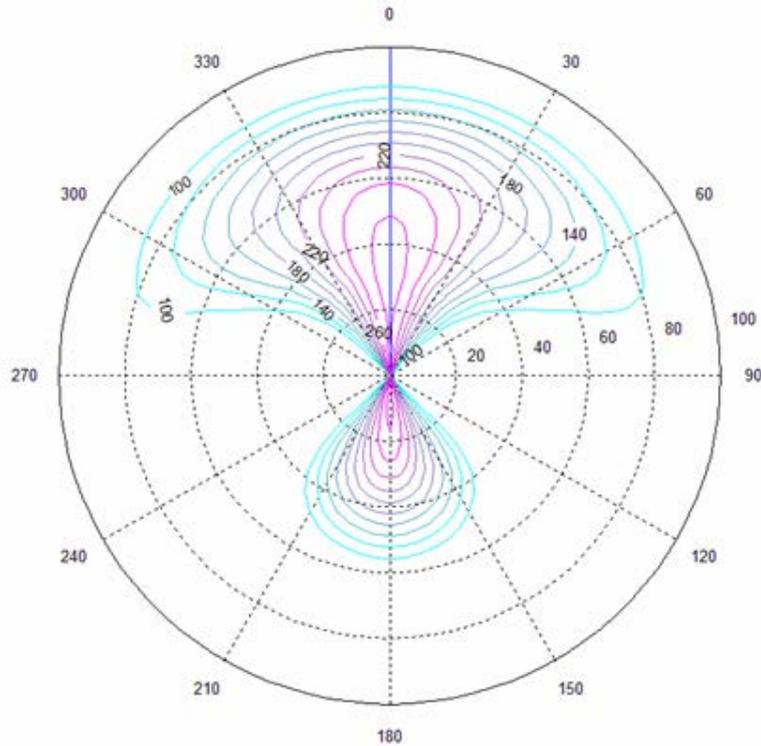
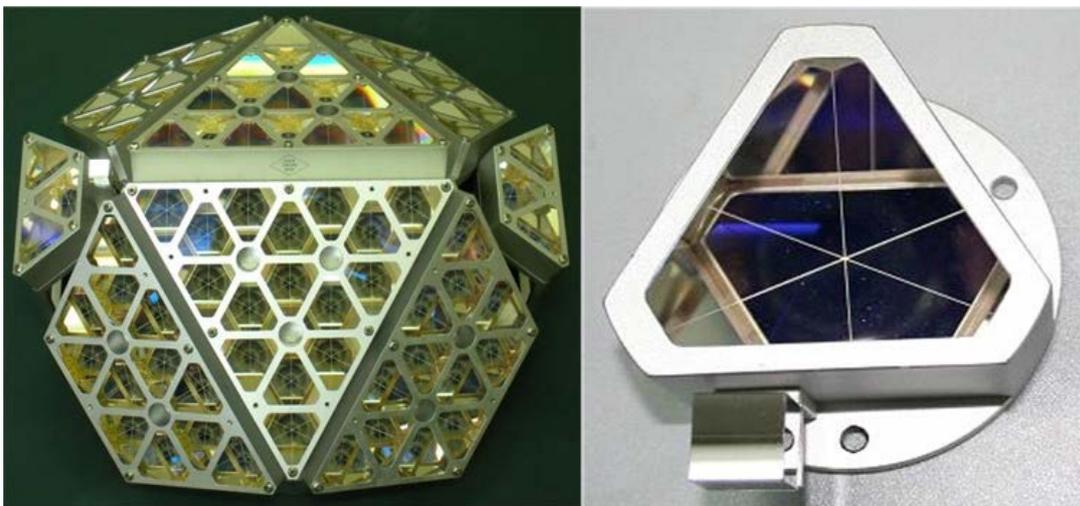


Fig.3 Effective reflective area of far field laser retro-reflector

For assessing whether the designed reflector could meet the requirements of TG-1 docking mission, we calculated the effective reflective area of the far field laser retro-reflector (Fig.3 ) relation to the azimuth and elevation under the coordinate and the origin fixed at the reflector (X axis directs the spacecraft moving direction). For the far field laser reflector, the main characteristics are following: 1) the effective reflective area over 180cm<sup>2</sup> when the azimuth and elevation are  $\pm 30$  deg and  $-25 \sim 70$  deg respectively; 2) the effective reflective area over 100cm<sup>2</sup> when the azimuth and elevation are  $\pm 45$  deg and  $-25 \sim 70$  deg respectively; 3) The total of weight is about 8.6kg. For the near field laser retro-reflector, the effective reflective area was over 15cm<sup>2</sup> with the weight of about 0.18 kg. Fig. 4 shows the photos of laser retro-reflector installed on TG-1 spacecraft.



(A) The far field laser retro-reflector

(B) The near field laser retro-reflector

Fig.4 The photo of laser retro-reflector in lidar measuring system

### 3. Applications in the TG-1 docking mission

After meeting docking mission requirements and passes all of space environmental simulation checks, the laser retro-reflectors were installed on the surface of TG-1 spacecraft launched on 09/29/2011. The SZ-8 spacecraft carrying lidar measuring system was launched on November 1, 2011. At the local time of 1h43min on November 3, the two spacecrafts, TG-1 and SZ-8, successfully realized the first unmanned automatically rendezvous and docking. Fig.5 and Fig.6 show the scenes of rendezvous and docking between TG-1 and SZ-8 from CCTV screen.



**Fig.5 The docking between TG-1 and SZ-8**

**Fig.6 The installed position of laser reflector on TG-1 spacecraft**

The manned SZ-9 and SZ-10 spacecrafts were launched on June 16, 2012 and on June 11, 2013 respectively. The spacecrafts successfully conducted manned, automatic docking with TG-1 on June 18, 2012 and on June 16, 2013. The new generation of Tiangong spacecraft will also adopt the same way for the future docking missions.

### 4. Summary

Due to its high precision advantages, the lidar system was also applied to accurately measure distance between TG-1 and SZ spacecrafts for the first spacecraft docking mission in China. To meet the requirements of dock mission, Shanghai Observatory successfully designed laser retro-reflectors with the FOV up to  $90 \times 105$  deg and the min. Reflective area over  $100\text{cm}^2$  at the distance of more than 20km. The key roles have been played for the applications of lidar measuring system in the docking mission of TG-1 spacecraft. The future docking missions in China will still adopt the same technique with the laser retro-reflector.

### References

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