Optical Tests of a Large Number of Small COTS Cubes

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Abstract

The use of small Commercial off-the-shelf (COTS) cubes for future satellite missions appears attractive for their comparatively low price per piece and ready availability when being compared to prisms that were specifically manufactured according to tight specifications. The question arises if the optical quality of such COTS cubes meets the requirements of satellite laser ranging.

The Institute of Aeronautics and Astronautics of Technische Universität (TU) Berlin recently purchased nearly 100 coated 10 mm cubes from a Chinese manufacturer for use in several nanosatellite projects. All samples were optically tested at GFZ Potsdam for their FFDPs. Additionally; ZYGO interferometric data for dihedral angle offsets are available for 32 samples. Tests of the "absolute" effective cross section with respect to a reference flat were performed for selected samples from the overall set. The results allow for collecting statistics about manufacturing tolerances and optical quality of the tested COTS cubes.

Motivation

As custom-made cubes with tight specifications with respect to the dihedral angle offset are expensive, corner cubes can easily become a cost driver for a given satellite mission especially if the number of required cubes is high. An alternative solution for laser retro reflectors on Low Earth Orbit (LEO) missions would be the use of very small Commercial-off-the Shelf (COTS) cubes without any specification for such an offset which rely on the broadened central lobe of the far field diffraction pattern (FFDP). The range of velocity aberration for a typical LEO orbit (600 km circular, near-polar) is in the range of about 30-50 µrad. In order to ensure that the optical quality of such COTS cubes meets the requirements of the mission, optical tests of the FFDP have to be carried out. A stock of nearly 100 corner cubes which were recently purchased by TU Berlin offered the opportunity to perform such tests and to compare the results with interferometric measurements of the actual dihedral offsets (which should be zero for a perfectly manufactured corner cube).

Optical test setup

Recording of the FFDP of the individual corner cubes (CCR) was performed on the in-house test bed of GFZ Potsdam (cf. Fig. 1).

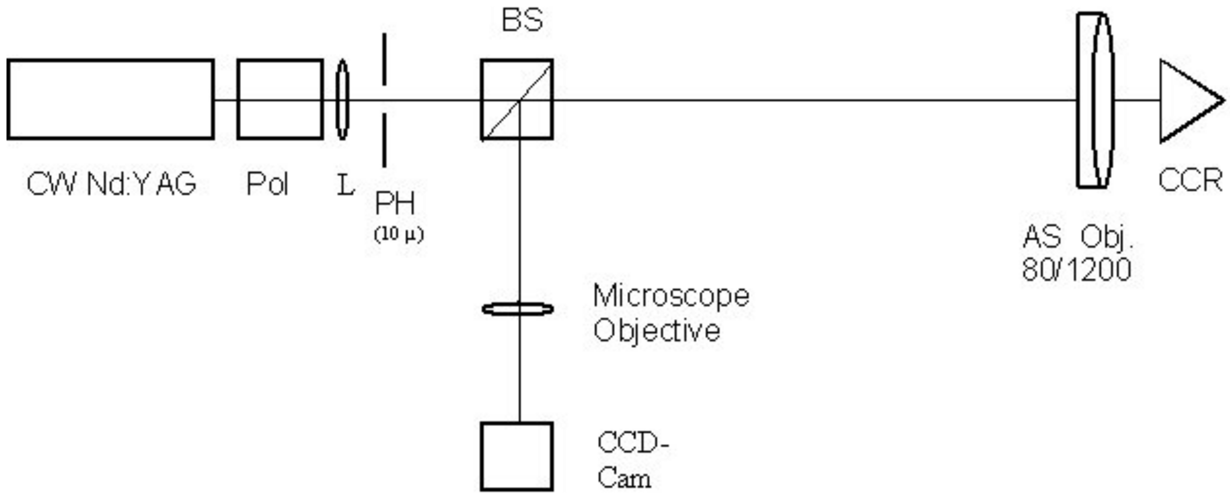

Figure 1 : Optical test bed for FFDP recording

A frequency-doubled CW Nd:YAG laser illuminates a small pinhole PH which is located exactly in the focus of an astronomic 1200 mm lens. The device under test (i.e. the CCR) is located in the parallel light behind this lens which performs the far field transformation. The FFDP of the CCR is coupled via a beam splitter (BS) and a microscope objective into a commercial CCD camera and read out via a PC.

The angular scale calibration of the setup is performed by replacing the CCR with a double slit in front of a high quality flat mirror. The recorded far field of the double slit is then compared to the theoretical distribution for the given parameters of the double slit and a calibration constant in µrad/pixel is derived.

The recorded FFDP's of some cube corners are compared with the Airy pattern of a circular mirror of same diameter. The patterns are normalized in a way that the sum of all intensities of both the Airy function and the measured FFDP within a field of 200 x 200 µrad is assumed to be equal. This allows the calibration of the scale in terms of the radar cross section.

The FFDP of a circular aperture equals the Airy function. The optical cross section at the center of the diffraction pattern of the circular aperture equals

$$c = 4\pi \left(\frac{A}{\lambda}\right)^2 = \frac{\pi}{4}\left(\frac{\pi \cdot D^2}{\lambda}\right)^2$$

(λ – Laser wavelength = 532 nm, D-aperture diameter=10 mm). For a 10 mm aperture this cross section is about 0.274 million square meters.

FFDP results

A total of 95 CCRs from *Changchun Hengrun Optoelectronics Tech Co. Ltd* was purchased in two lots by TU Berlin for the use in two nanosatellite projects, namely the TechnoSat and the S-Net mission [1, 2]. The corner cubes are made from JGS1 fused silica with an aperture of 10 mm and are backside coated by silver. ZYGO interferometric measurements are available for the second lot (sample No. 63 – 95). The following figures show the far field diffraction patterns for the individual samples, plotted for a field of 200 x 200 µrad each. The yellow-bordered images were obtained from the optical reference flat and yield for comparison.

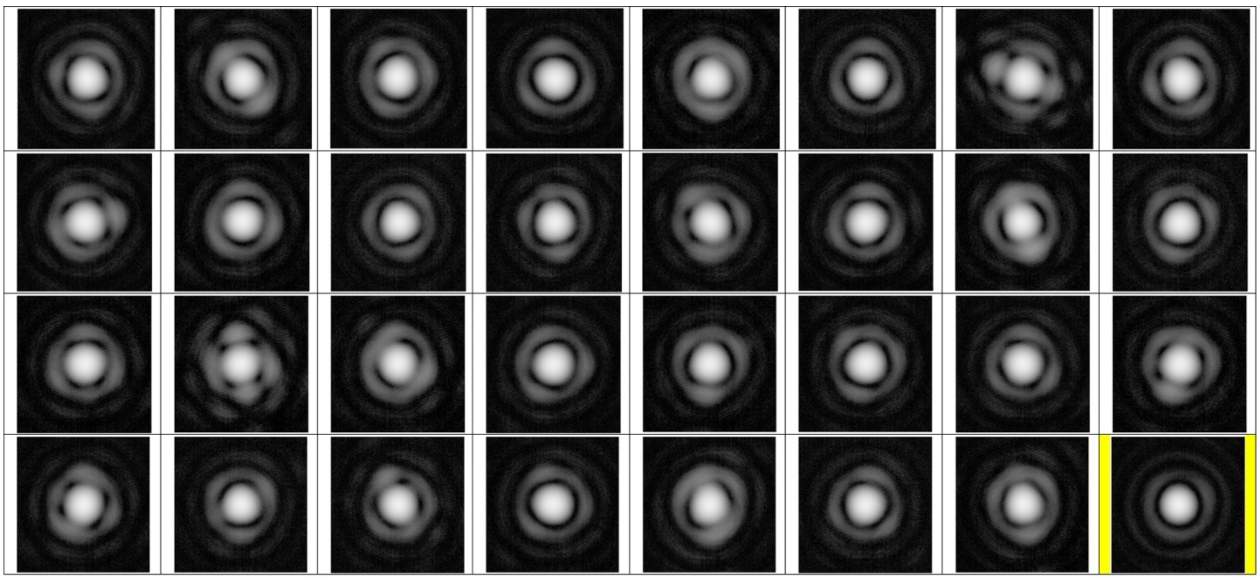

Figure 2: FFDPs for corner cube samples 01 – 31

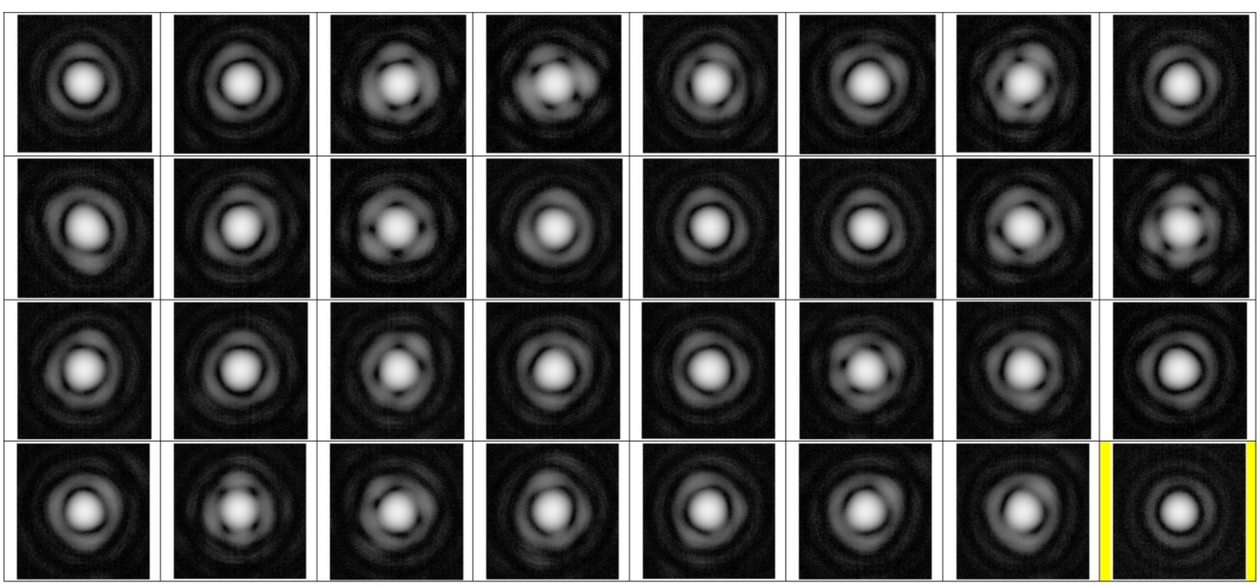

Figure 3: FFDPs for corner cube samples 32-62

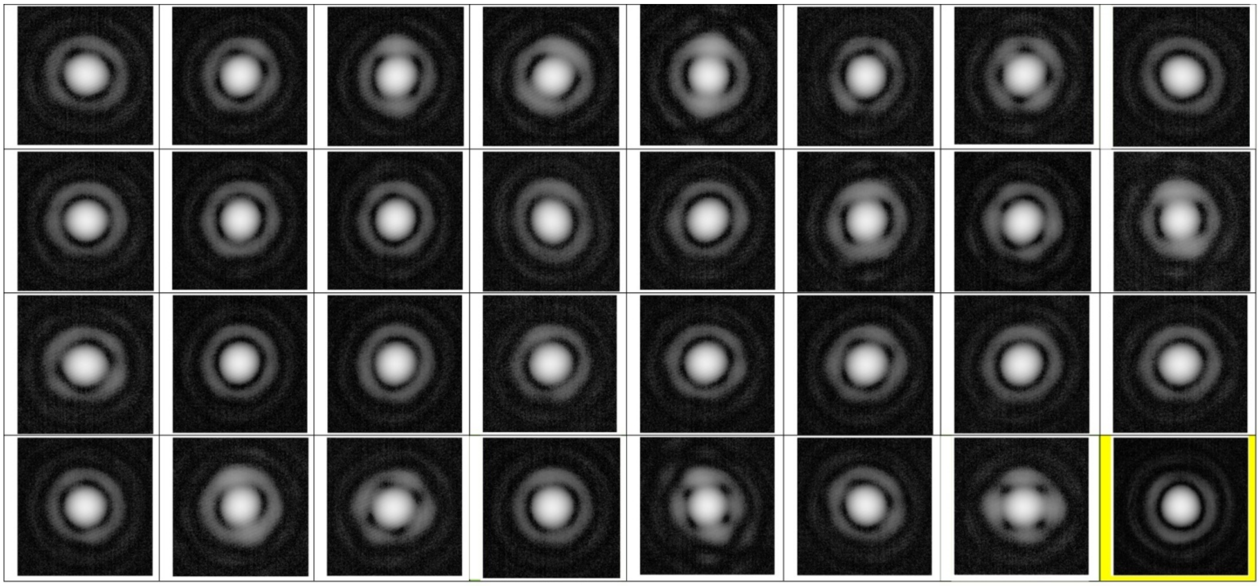

Figure 4: FFDPs for corner cube samples 63-93

The ZYGO interferometric measurements of the dihedral angle offsets were performed in the single pass technique [3] because of the small size of the corner cubes. They showed that most of the offsets are within the limits of ±1 arc second (cf. Fig. 5) and are thus in good agreement with the observed rather smooth and symmetric far field diffraction patterns.

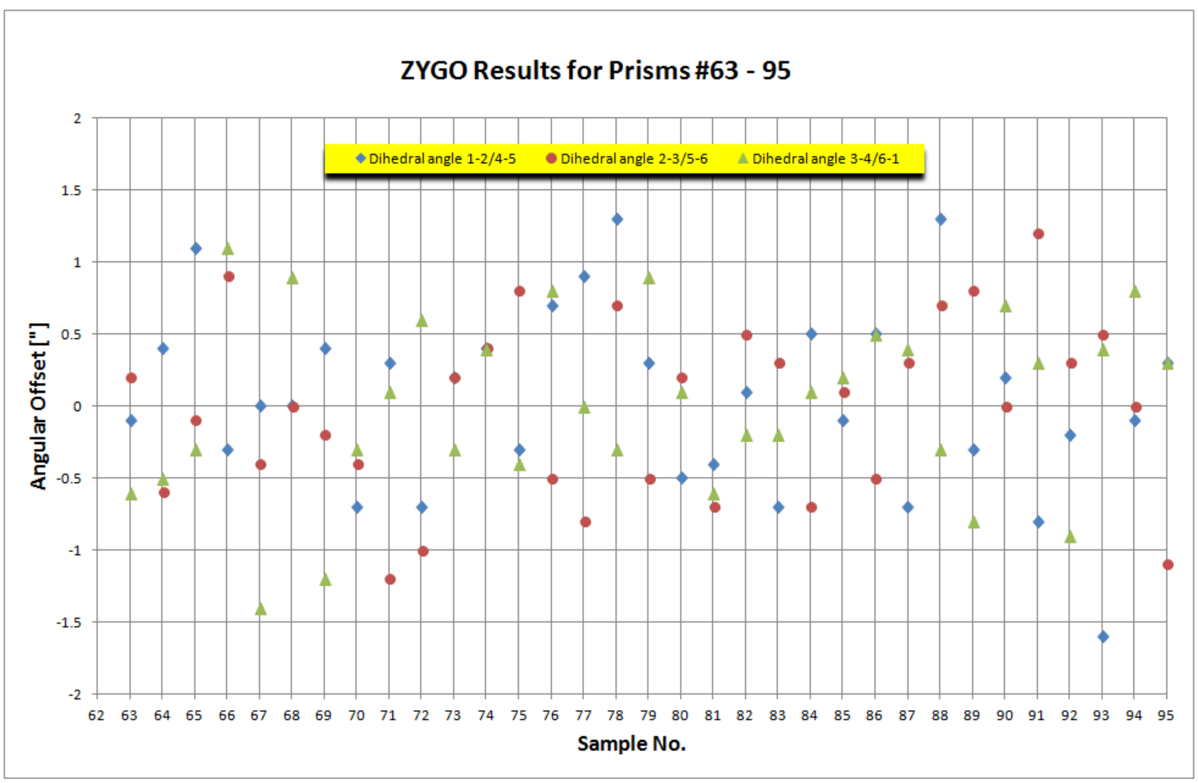

Figure 5: Dihedral angle offsets for corner cube samples 63-93 from ZYGO data

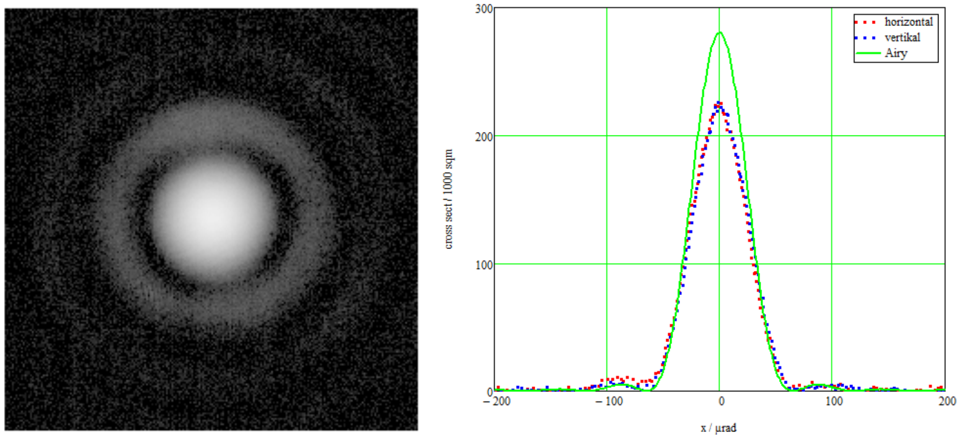

Fig. 6: FFDP and fit to theoretical Airy pattern for CCR no. 90

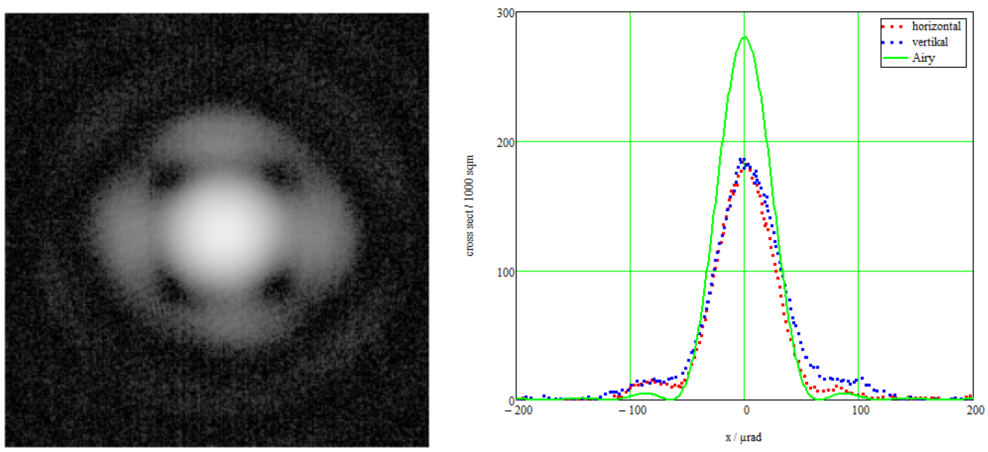

Fig. 7: FFDP and fit to theoretical Airy pattern for CCR no. 93

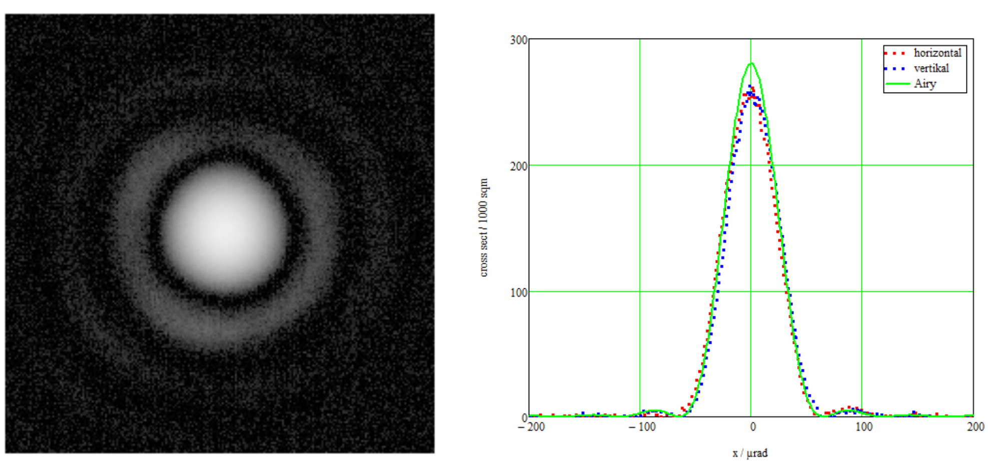

Fig. 8: FFDP and fit to theoretical Airy pattern for the Optical Reference Flat

The Figures 6 – 8 show FFDP in comparison with the theoretical Airy pattern for a perfect circular aperture for two selected corner cubes and the reference flat in more detail. Note that any reflection loss is not taken into account. CCR #90 shows very small dihedral offsets, CCR #93 has two of those offsets positive and one negative, exceeding 1.5 arc seconds.

Conclusions

Most of the tested COTS CCRs show quite acceptable, symmetric far field diffraction patterns and only slightly reduced peak optical cross sections as compared to the optical reference flat. The slight broadening of the central lobe with respect to the reference flat is even favorable with respect to signal strength because the available cross section within the aberration range of interest for a LEO orbit (30 – 50 µrad) is several 10^4 square meters. This is considered sufficient to establish a reliable optical link for laser ranging. In case there are ZYGO data for the dihedral angle offsets available, these data give a good hint for the expected quality of the FFDP.

The use of COTS cubes from the tested lot for the purpose of laser ranging to LEO satellites can be recommended.

References:

[1] M. Barschke, K. Gordon, M. Lehmann and K. Brieß, 'The TechnoSat mission for on-orbit technology demonstration', presented at the 65th German Aerospace Congress, Braunschweig, Germany, 2016.

[2] Z. Yoon, W. Frese, A. Bukmaier and K. Brieß, 'System Design of an S-Band Network of Distributed Nanosatellites', CEAS Space Journal, vol 6, iss. 1, pp. 61-71, 2014.

[3] ZYGO® MetroPro Application Corner Cube OMP-0384C

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