月面コーナーキューブの光学応答解析

Optical Response Simulation of Corner Cube Reflectors for SELENE2 Mission

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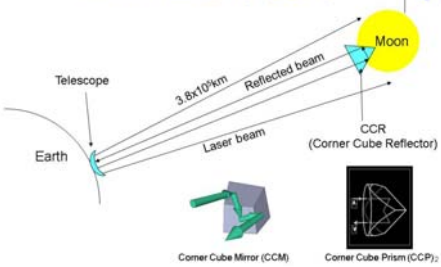
Introduction

- The object of these simulations is clearing up the criterion for Corner Cube Prism (CCP) and Corner Cube Mirror (CCM) in order to measuring the distance from the Earth to the moon in cm order.
- In case of CCP, refractive index inhomogeneity restrict its size to small (~10cm), so not calculate the effect of any deformation.
- In case of CCM, calculate both effects of moon gravity deformation and thermal deformation.
- Optical responses are calculated with CodeV (Synopsis, Inc.)
- Not considering DAO (Dihedral Angle Offset), because common optical simulation software cannot calculate its effect.
- Optical response criterion is that the encircled energy within 3.5μrad (half angle) > 50%, where 3.5μrad is equal to the minimum deflection by velocity aberration without DAO.
- The velocity aberration deflect 3.5-7μrad from Laser emitted direction according to the relative speed between the Earth and the moon.

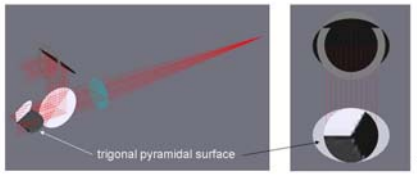
Schematic View of Lunatic Laser Ranging (LLR)



1. Homogeneity Analysys of CCP

1-1. CCP modeling with one surface

Commonly CCP is modeled with three non-sequential surfaces, but in this case, it's very difficult or impossible to consider homogeneity together, because CCP is consisted with three materials. So I use the trigonal pyramidal surface as a User-Defined Surface shown as below.

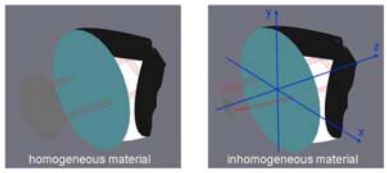


*Trigonal Pyramidal Surface macro is supplied from Cybernet Co., Ltd.

1. Homogeneity Analysys of CCP

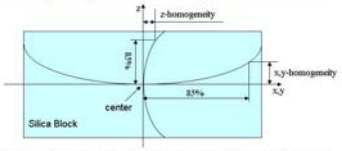
1-1. CCP modeling with one surface

This means that the CCP is modeled with trigonal pyramidal surface and reflected three times on this one (same) surface. In this case, the material of CCP is only one so it's very easy to consider the in-homogeneity material.



1. Homogeneity Analysys of CCP

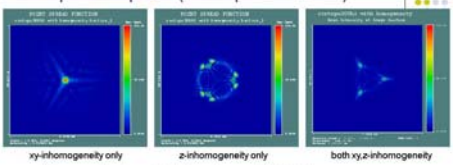
1-2. Homogeneity Definition for Synthesized Silica



- Both in surface direction (x,y) and in axial direction (z), the homogeneity is defined at 85% range of the outer size
- Distributions of homogeneity are well fitted with quadratic functions, and those the peaks almost coincide with the center of silica block.
- If x,y=150mm, even best quality silica has 3ppm inhomogeneity at 127.5mm point
- If z=80mm, it has 2ppm@68mm, if z=150mm, it has 7ppm@127.5mm

1. Homogeneity Analysys of CCP

1-3. Optical Response (Point Spread Function)



- xy-inhomogeneity 3ppm@127.5mm is acceptable (left)
- z-inhomogeneity is very effective and 0.4ppm@68mm is needed instead of 3ppm@68mm (center)
- z-direction thermal gradient is also very effective (not shown), less than 0.23degree is needed
- As a result, the max. size of Corner Cube Prism is around 10cm
- If bigger Corner Cube Reflector is needed, only Corner Cube Mirror can be used

2. Deformation Analysis of CCM

2-1. Simulation Method and results

- Thermal deformation and Gravitational deformation are calculated independently
- Deformation information are calculated with FEM by other members (see other poster)
- Deformation data are fitted to the Zernike surface with codev
- Three surfaces are fitted to different deformation data if need
- Optical Responses are evaluated with PSF (Point Spread Function), encircled energy (enc), BPR (Beam Propagation = FFT method), and BSP (Beam Synthesis Propagation method)

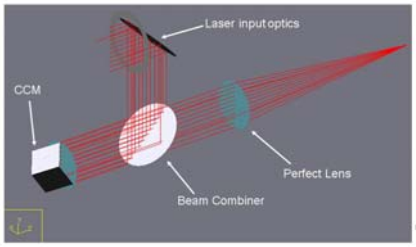
	mg5	mg10	mg15	200t5	200t10	200t15	100t5	100t10	100t15	
wfa	0.0087	0.0024	0.0012	0.0244	0.0106	0.0063	0.0014	0.0011	0.0007	
sd	0.9970	1.0000	1.0000	0.9770	0.9960	0.9980	1.0000	1.0000	1.0000	acceptable
50%enc	0.0030	0.0029	0.0029	0.0102	0.0047	0.0032	0.0057	0.0057	0.0057	
90%enc	0.0118	0.0105	0.0105	0.0195	0.0135	0.0116	0.0207	0.0207	0.0207	

- mg5 represents "moon gravity deformation and mirror thickness 5mm", others follow in the same manner
- Moon gravity deformations cases all adopt diameter ϕ200mm because ϕ100 is previously better
- 200t5 represents diameter is ϕ200mm and mirror thickness 5mm
- wfa means wave front aberration, sd is Strehl Density, enc is encircled energy
- Critical value is enc>50% in 3.5μm (=0.0035 in above table) in diameter

2. Deformation Analysis of CCM

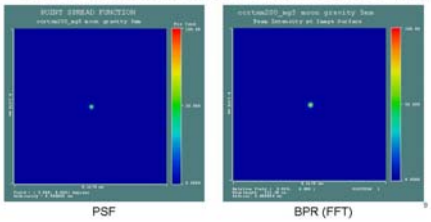
2-2. Simulation Optical System

Calculate optical response with the below optical system that is an experimental set up, not earth <-> moon system.

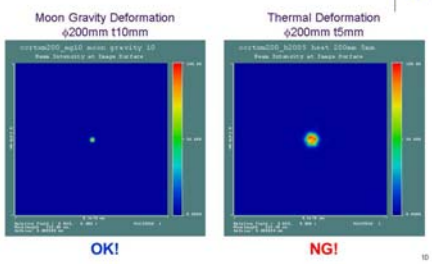


2.3 Some Results PSF vs. BPR

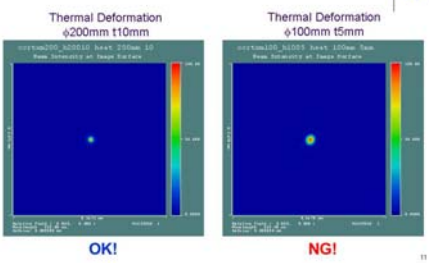
- Below figures are results with PSF and BPR (FFT) for Moon Gravity ϕ200mm, t5mm
- Both results are well coincide, so after this, show BPR only



2.3 Some Results with BPR

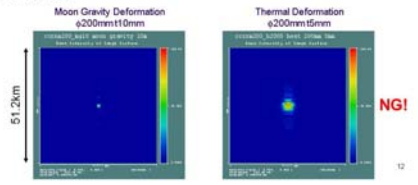


2.3 Some Results with BPR

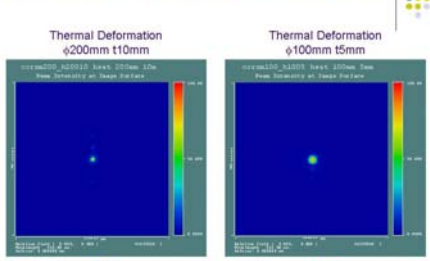


2.4 From Earth to Moon Actual Simulation

- Before calculations are in experimental setup, but here, I'll show some calculation results for the actual setup, i.e., from the Earth to the moon, reflected on the moon, received on the Earth.
- In this case, there is no optical component, so I used BPR and BSP instead of PSF. The effect of the Laser beam divergence is included.



2.4 From Earth to Moon Actual Simulation



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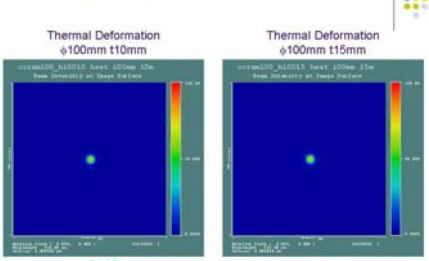

3. Conclusion

- 200t5 is NG and 200t10, 100t5, 100t10, 100t15 is on border line.
- 200t5 and 200t10's low responses are caused by aberration, but ϕ100t series' low responses are caused by Laser beam divergence because their apertures are half small.
- In this point of view, the efficiency of the small aperture CCM is down compared with large aperture CCM.

	200mg5	200mg10	200mg15	200t5	200t10	200t15	100t5	100t10	100t15
3.5urad	60.765	61.885	62.763	17.340	50.270	58.284	52.836	51.757	51.130
50%	2.150	2.055	2.021	6.760	3.465	2.345	3.340	3.300	3.430
7.0urad	-	-	-	-	-	-	71.972	70.133	69.899

- 3.5μrad means encircled energy within 3.5μrad
- 50% means solid angle for energy 50%
- 7μrad means encircled energy within 7μrad