Digital holographic interferometry in the long-wave infrared for the testing of large aspheric space reflectors

J-F. Vandenrijt[1], C. Thizy[1], Y. Stockman[1], P. Queeckers[2], F.Dubois[2] D. Doyle[3], M. Georges[1]

1. Centre Spatial de Liège, Liege Science Park, 4031 Angleur, Belgium
2. Microgravity Research Center, Université Libre de Bruxelles, CP165/62, Av. Franklin Roosevelt 50, 1050 Brussels, Belgium
3. ESA-ESTEC, TEC-MMO, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

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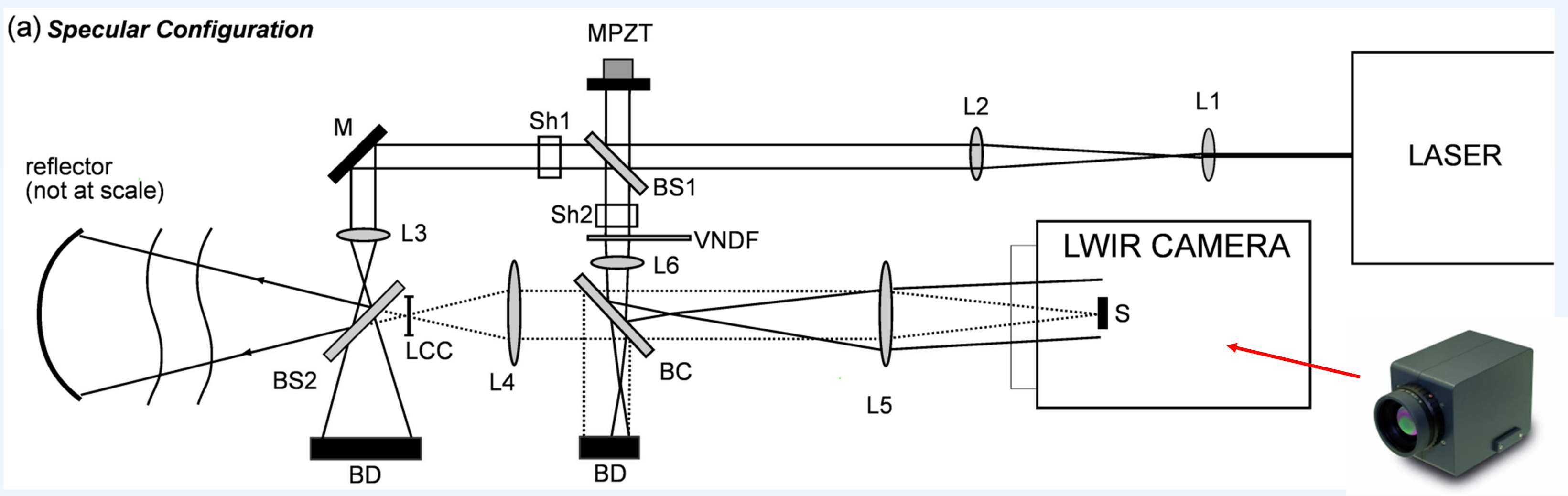
Abstract

Digital Holography (DH) in the Long-Wave InfraRed (LWIR) range shows an increased interest since its first demonstration in 2003 [1]. In particular it allows observing large objects due to the fact that at such wavelengths the ratio between the wavelength and the pixel size allows reconstructing objects 5 to 10 times larger than with DH in visible light [2,3]. We already presented various configurations of LWIR DH interferometry and electronic speckle pattern interferometry for deformation metrology and non destructive testing [3,4]. In this paper we present the application of LWIR DH in interferometric testing of large deformation of large aspheric mirrors in the frame of a European Space Agency project. Here the study focuses on the case of parabolas and ellipses which are usually tested through interferometric wavefront error measurements which require expensive null-lenses matching each of the reflectors considered. In the case of monitoring deformation a holographic technique can be considered where the wavefront is compared with itself at different instants. Therefore the optical set-up can be quite simple and easily reconfigurable from one reflector to another. The advantage of using long wavelength is that large deformations can be measured at once, in addition to being more immune against environmental perturbations. In this paper we review different optical configurations of DH interferometer that led to test a parabolic mirror under thermal-vacuum test [5], as well as an off-axis ellipse tested in laboratory conditions, which is a new result.

Study of 2 configurations with parabolic reflector: *specular* vs. *scattering*

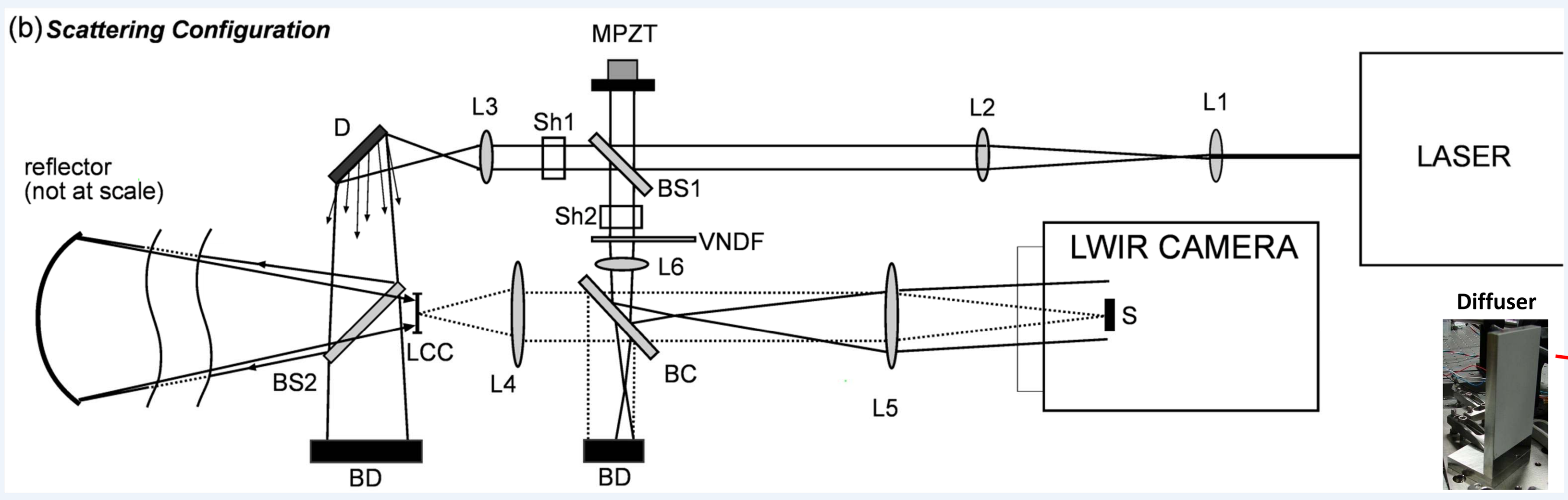
Two similar set-up, except for object illumination

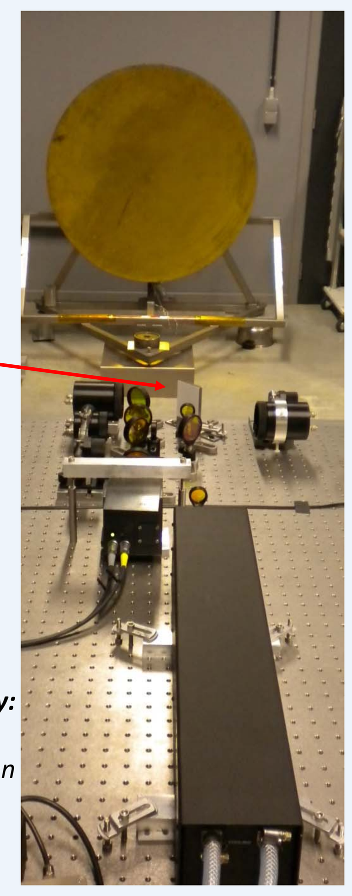
Set-up to be further placed under vacuum chamber for space environment simulation



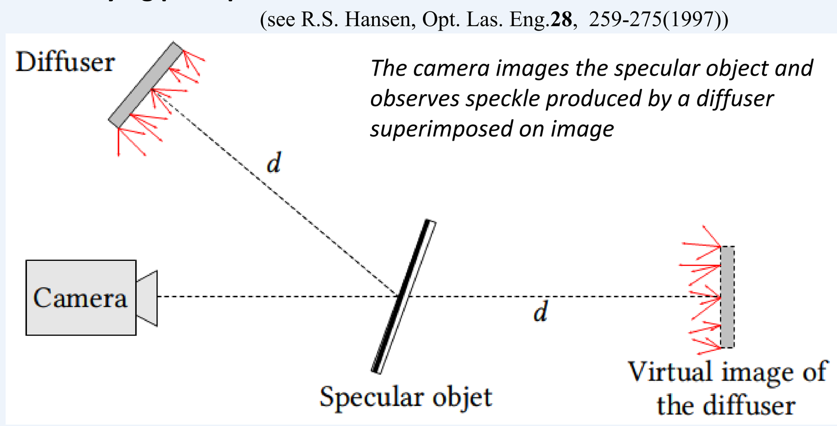
Uncooled µ-bolometer
640x480 pixels
Pixel Pitch : 25 µm
Frame rate 60 Hz

- Single point illumination (focus of L3)
- After reflection by parabola, no refocusing in single point but Least Confusion Circle (LCC)
- LCC imaged on camera sensor and interferes with reference beam
- Digital holography reconstruction by Fresnel Transform

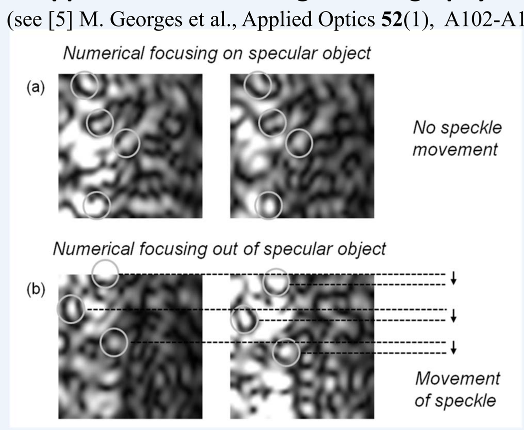




Underlying principle : ESPI on mirrors with diffuse illumination
(see R.S. Hansen, Opt. Las. Eng.28, 259-275(1997))

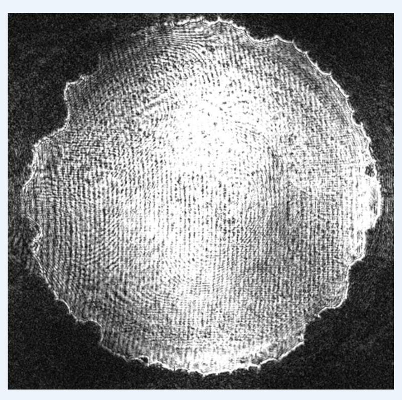


Application to LWIR Digital Holography
(see [5] M. Georges et al., Applied Optics 52(1), A102-A116 (2013))

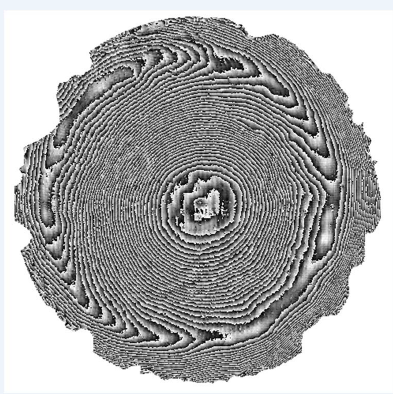


In Digital Holography: Same as in ESPI but numerical focusing on specular object

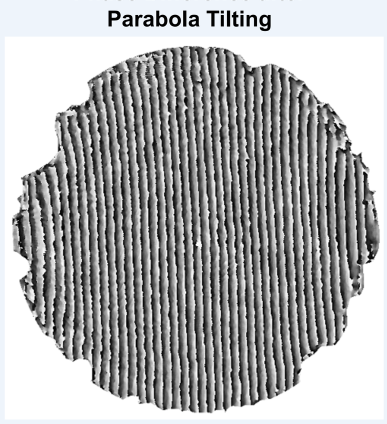
Reconstructed Amplitude



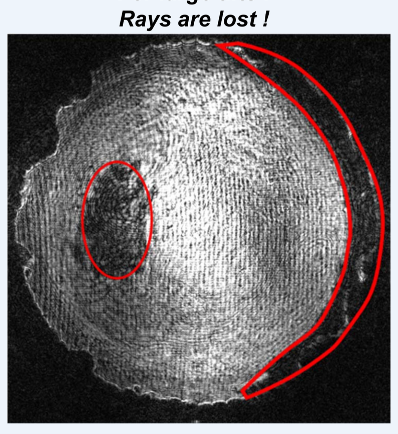
Reconstructed Phase



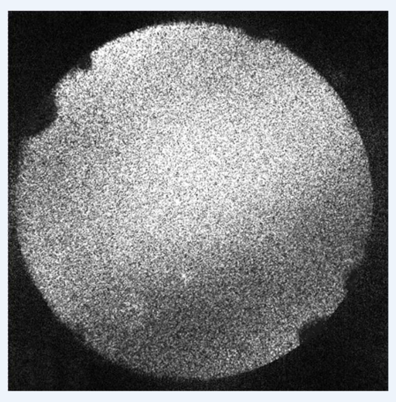
Phase Difference after Parabola Tilting



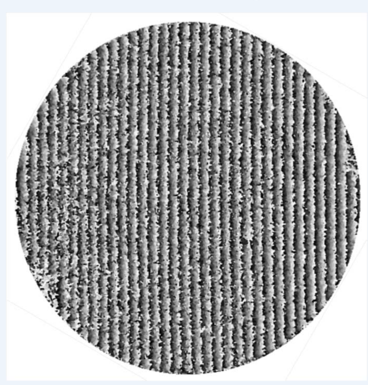
For large tilts : Rays are lost !



Reconstructed Amplitude



Phase Difference after Parabola Tilting

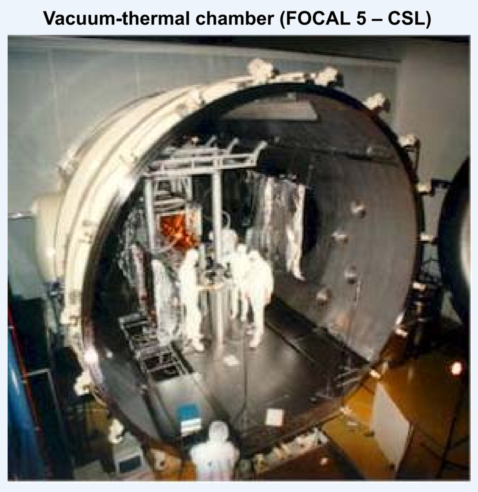


Comparison between configurations

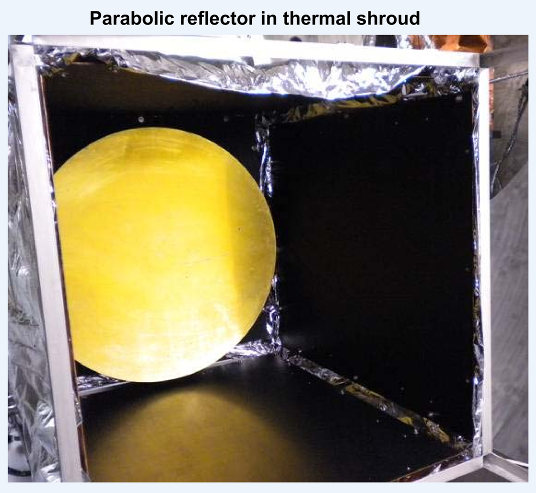
- Specular
  - Higher quality
  - Laser power: 70 mW
  - **Large tilts not allowed**
- Scattering
  - Easier alignment
  - Laser power: 700 mW
  - Versatility when change of test object

Scattering configuration in vacuum-thermal testing

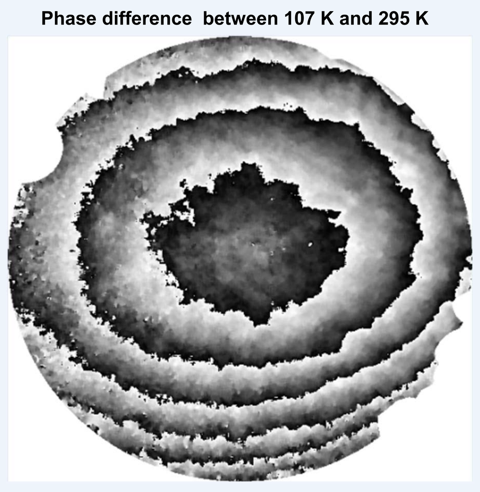
Vacuum-thermal chamber (FOCAL 5 – CSL)

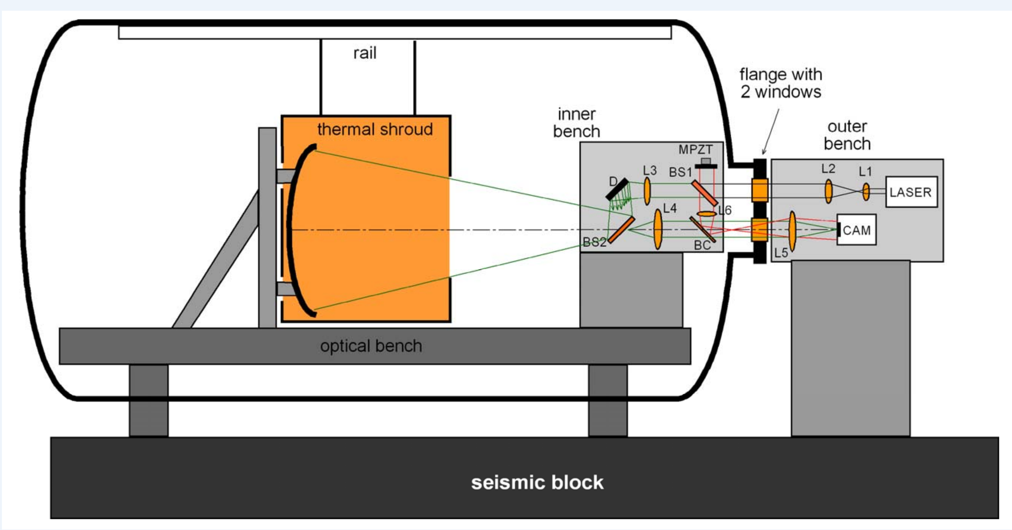


Parabolic reflector in thermal shroud

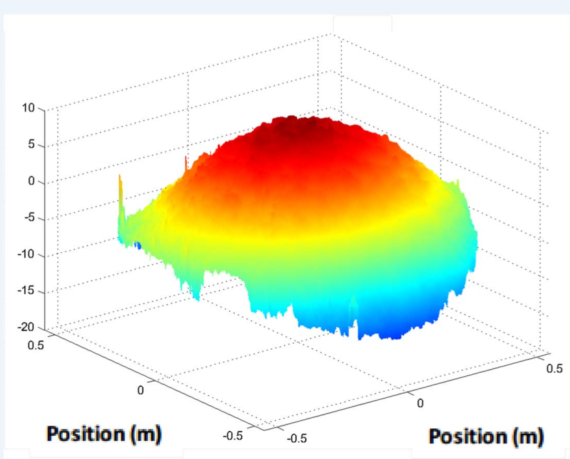


Phase difference between 107 K and 295 K



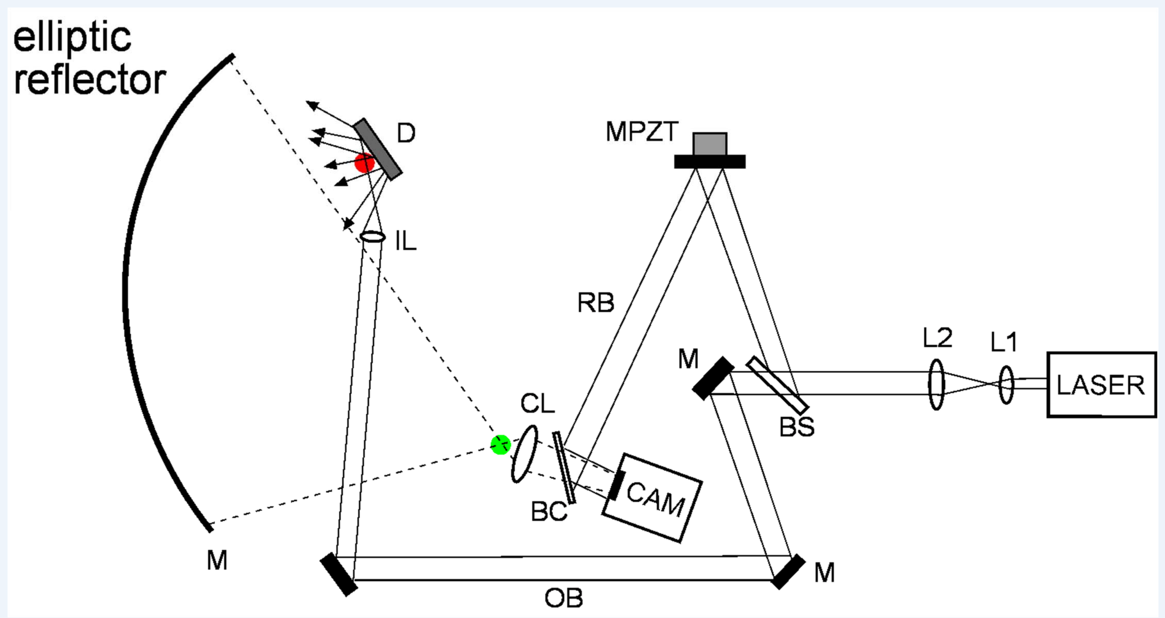


Deformation of reflector between 107 K and 295 K

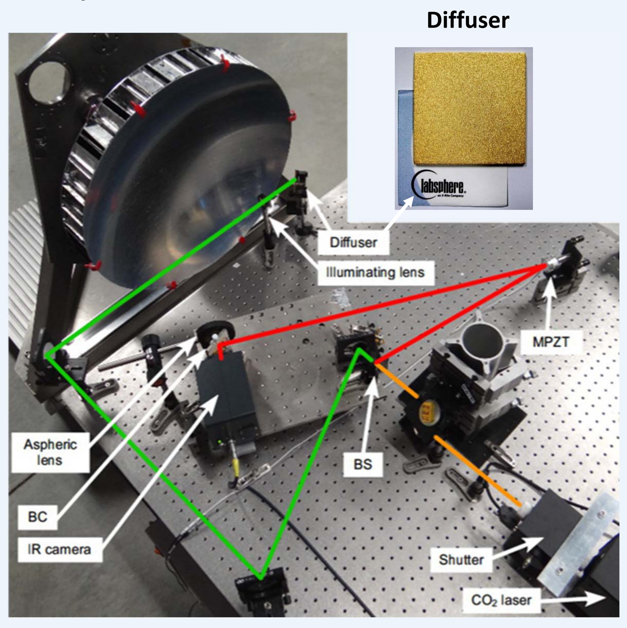


Laboratory testing of elliptic reflector

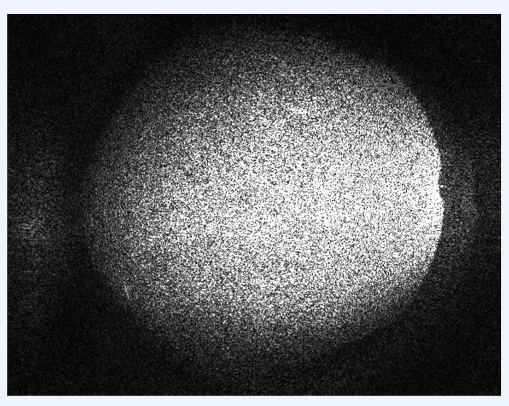
Specimen : PLANCK secondary elliptic reflector (demo version)



Diffuser

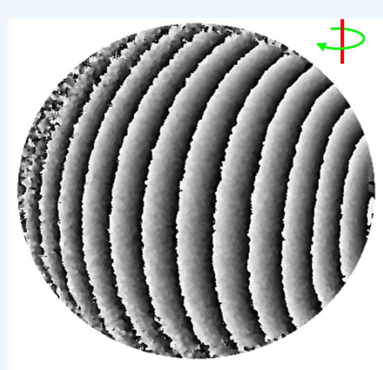


Reconstructed Amplitude

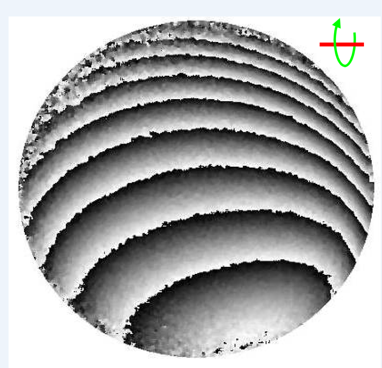


Phase difference

after horizontal tilt



after vertical tilt



- DH in scattering illumination configuration
  - Easy alignment
  - Use of COTS elements (no need of specific lenses)
  - Much simpler than classical interferometry

Conclusion

Long Wave InfraRed Digital Holography for testing aspherics has been demonstrated:

- It uses COTS elements for more versatile and easier set-up if compared to conventional interferometry which requires expensive null-lenses.
- It allows large deformation measurements with highly stability in industrial environments (due to the long wavelength).
- Two illumination configurations were compared. Use of a diffuser (scattering configuration) allows easy working with various aspheric reflectors with high tolerance to misalignment.
- Successful measurements on large specular aspherics (parabola and ellipse) have been demonstrated in vacuum-thermal testing.

References

[1] Allaria, E, Brugioni, S, De Nicola, S, Ferraro, P, Grilli, S, Meucci, R (2003) Digital holography at 10.6 µm, Optics Communication 215, 257-262

[2] Pelagotti, A, Paturzo, M, Geltrude, A, Locatelli, M, Meucci, R, Poggi, P, Ferraro, P, (2010) Digital holography for 3D imaging and display in the IR range: challenges and opportunities, 3D Research, Springer Publishing 1(4), 1-10

[3] Vandenrijt, J-F, Georges, M.P. (2010) Electronic speckle pattern interferometry and digital holographic interferometry with microbolometer arrays at 10.6µm, Applied Optics 49(27): 5067-5075

[4] Alexeenko, I, Vandenrijt, J-F, Pedrini, G, Thizy, C, Vollheim, B, Osten, W, Georges, M P (2013) Nondestructive testing by using long-wave infrared interferometric techniques with CO2 lasers and microbolometer arrays, Applied Optics 52(1): A56-A67

[5] Georges, M P, Vandenrijt, J-F, Thizy, C, Stockman, Y, Queeckers, P, Dubois, F, Doyle, D (2013) Digital Holographic Interferometry with CO2 lasers and diffuse illumination applied to large space reflectors metrology, Applied Optics 52(1), A102-A116