International Commission for Optics ICO 21 – 2008 Congress

Optics for the 21st Century

SYDNEY CONVENTION & EXHIBITION CENTRE, SYDNEY, AUSTRALIA
Monday 7 – Thursday 10 July 2008

Book of Proceedings

ISBN: 0 85825 815 3

Hosted by:

AUSTRALIAN OPTICAL SOCIETY
ENGINEERS AUSTRALIA
ICO CIO

Endorsed by:

OSA Optical Society of America

Cooperating Society:

SPIE

This Conference is supported by the Australian Government under the

Stationary and non-stationary deformations in three-flat tests

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Abstract: Calibration procedures for optical reference flats of phase-shifting interferometers (*three-flat tests*) are critically important if flatness measurements with low uncertainty are desired. In these tests, all combinations of three flats with unknown flatness error are measured and the flatness errors of all three flats are determined [1]. In a three-flat test procedure, at least one of the flats must be rotated [1]. The forces of the flat mount on the optical flats lead to deformations of the flat surfaces. The deformations may be stationary when the flat is rotated, or, when an asymmetry is present, they may change when the flat is rotated. For the widely used reference flats with diameters up to 150 mm, the deformations are often negligible. For larger and heavier flats the flatness error due to the deformation can much exceed the uncertainty of the calibration, even when the flats are mounted on their edge, and it must be accounted for accurately. We illustrate this with measurements and finite element calculations for optical flats made from fused silica with a diameter of 300 mm. The form error of the flats is 30 nm peak-valley. The flats are bonded with a silicone adhesive in to an aluminium hoop which can rotate in three V-bearings. Two of the bearings below the flat bear the combined weight of hoop and flat (150 N), the third bearing at the top of the flat constrains the flat but exerts no radial force. The mirror-symmetric component of the stationary flatness error, which has a magnitude of 5 nm peak-valley, can be measured as part of the calibration procedure [1]. This flatness error is a considerable fraction of the total flatness error. Non-stationary deformations are primarily the result of the slight wedge shape of the flat which causes a change in the mass distribution as the flat is rotated. They can not be determined in the three-flat test, but can have a significant effect on the calibration uncertainty. We have calculated the non-stationary deformation and resulting flatness error as a function of rotation angle using a three-dimensional finite-element (FE) model of the flat and its mechanical support structure. The smallness of the deformation compared to the size of the flat required a very fine mesh, especially for the non-linear silicone bonds, and a careful choice of boundary conditions to obtain FE model which agrees with measurements. The deformations of the flat were calculated for the rotation angles that are used in the calibration procedure. For the 300 mm flat in our mechanical mount the non-stationary deformations result in an uncertainty of 0.5 nm in the flat calibration results near the edges of the flats.

[1] Ulf Griesmann, Quandou Wang, and Johannes Soons, "Three-flat tests including mounting-induced deformations", Opt. Eng. 46, 093601 (2007)