Absolute interferometric measurement of non rotational symmetric surface errors

Günther Seitz

Carl Zeiss SMT AG, 73446 Oberkochen
mailto:g.seitz@smt.zeiss.com

The basic problem of absolute interferometric surface metrology is the separation of interferometer- and surface errors. This paper proposes a new approach for the separation of non rotational symmetric errors.

1 Introduction

Interferometric measurements, acquired by a setup similar to fig.1, always contain a superposition of interferometer and surface errors. Subject of this paper is the separation of the non rotational symmetric errors.

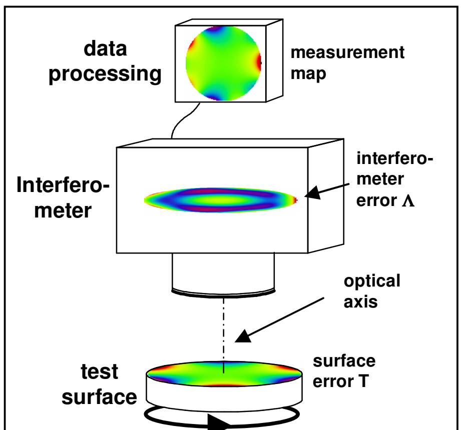

Fig 1: *test setup*

To distinguish between interferometer and surface errors, the test surface is rotated about the optical axis. Measurements are taken at N_α equidistant rotation angles.

2 Averaging Method

The most popular procedure to extract the surface error from these measurement maps is the Averaging Method. According to fig. 2, the measurement maps, obtained at the rotation angles α of the test surface, are rotated back by the same angles and averaged together.

Using the shift theorem of the fourier transform, the Averaging Method can be described in the azimuthal spatial frequency domain. The processing result $AM_{N\alpha}$ of the Averaging Method is given by equ. 1 with Λ being the interferometer error, k an integer (0, 1, 2,.., N_α-1), $\Delta\alpha$ (= $2\pi/N_\alpha$) the increment of the rotation angle α, T_α the test surface error rotated by angle α and f the azimuthal spatial frequency.

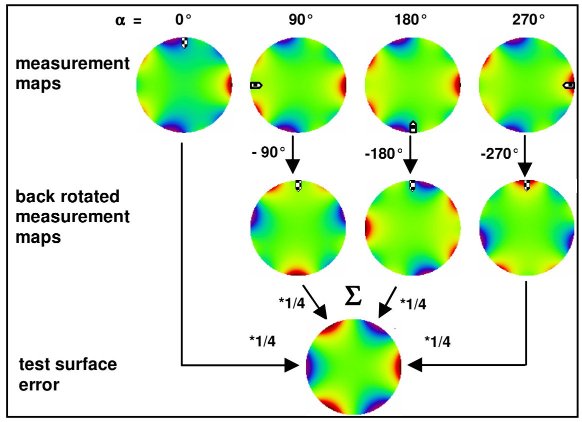

Fig 2: *Averaging method for N_α=4*

$$AM_{N\alpha} = \frac{1}{N_\alpha}\sum_{k=0}^{N_\alpha-1}\left[\Lambda + T_{k\cdot\Delta\alpha}\right]\cdot e^{-i\cdot 2\cdot\pi\cdot f\cdot\Delta\alpha\cdot k} \qquad (1)$$

Considering, that the test surface error $T_{k*\Delta\alpha}$ is rotated back by the same angle $\alpha=k*\Delta\alpha$, the test surface error is completely preserved. Therefore, the filter function, applied to the surface error is Γ_T = 1.

The appropriate filter function Γ_Λ for the interferometer error Λ is also obtained from equ. 1. Assuming drift stability of the interferometer error, we obtain the filter function Γ_Λ:

$$\Gamma_\Lambda = \frac{1}{N_\alpha}\sum_{k=0}^{N_\alpha-1} e^{-i\cdot 2\cdot\pi\cdot f\cdot\Delta\alpha\cdot k} \qquad (2)$$

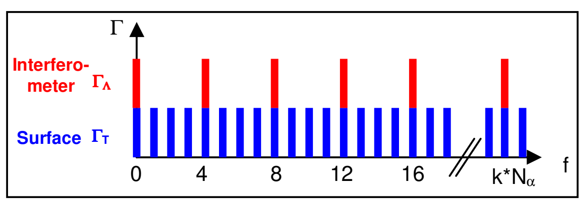

Fig 3: *filter function Γ; Averaging Method for N_α=4*

Starting from this analysis, we can identify several weak spots of the Averaging Method:

- **N_α-waviness:** According to fig. 3, frequencies of integer multiples of N_α from the interferometer error are still present in the processing result.

- Interferomter drift: If the interferometer error does not remain stable during the complete measurement series, equ. 2 is no longer valid. The filter function Γ_Λ of the interferometer error is extended by additional transmission lines.

- **Interpolation error:** Back rotation of the measurement maps is done by the data processing system, using interpolation. It can be shown, that the appropriate interpolation error can increase up to the %-range.

- **Axes misalignment:** If rotation axis of the test surface and the rotation center of the data processing system are misaligned, the back-rotation of the data maps is performed about the wrong center, causing artefacts and shearing errors.

To overcome all these problems, the Reconstruction Method is proposed.

3 Reconstruction Method

As shown in fig. 4, N_α-1 measurements M(α) are taken at angles α=q*$\Delta\alpha$ with q = 1, 2, … N_α-1. But in addition, every angular measurement is supplemented by one measurement M(0) at zero angle. The surface error is obtained by averaging over all differences of zero- and angular measurement maps, whereas no data maps have to be rotated.

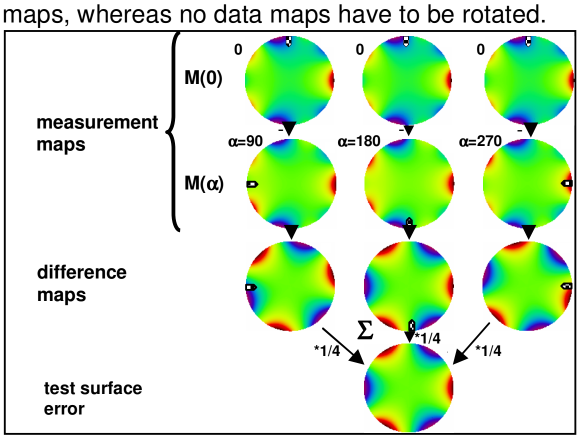

Fig 4: *Reconstruction Method for N_α=4*

The processing result $AR_{N\alpha}$ of the Reconstruction Method is given by equ. 3:

$$AR_{N\alpha} = \frac{1}{N_\alpha}\sum_{q=1}^{N_\alpha - 1}\left(\Lambda + T_0 - \Lambda - T_0 \cdot e^{i\cdot 2\cdot \pi\cdot f\cdot \Delta\alpha\cdot q}\right) \qquad (3)$$

The Interferometer-Error Λ is completely subtracted off with the corresponding filter function Γ_Λ = 0, while the azimuthal spectrum of the test-surface is modified by the filter function Γ_T:

$$\Gamma_T = \frac{1}{N_\alpha}\sum_{q=1}^{N_\alpha - 1}\left(1 - e^{i\cdot 2\cdot \pi\cdot f\cdot \Delta\alpha\cdot q}\right) \qquad (4)$$

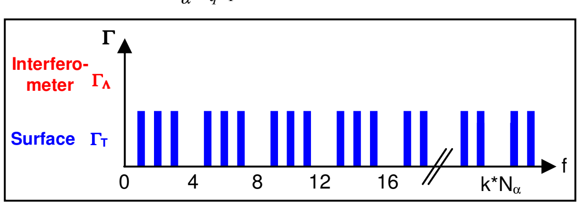

Fig 5*: filter function Γ; Reconstruction Method for N_α=4*

4 Comparison Averaging/Reconstruction

We performed measurements of a test surface, selecting N_α = 16 and evaluated the raw data maps according to Averaging- and Reconstruction Method. As shown in fig. 6, the Averaging output

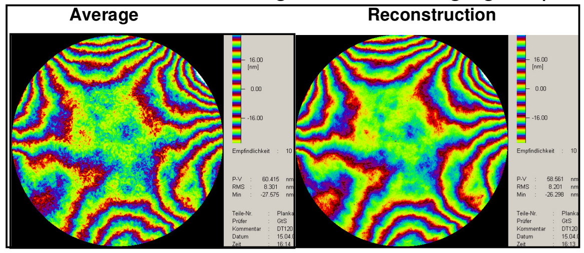

Fig 6: *comparison Averaging/Reconstruction Method*

seems to be more noisy. This is confirmed by the PSD-plots of both results, shown in Fig. 7.

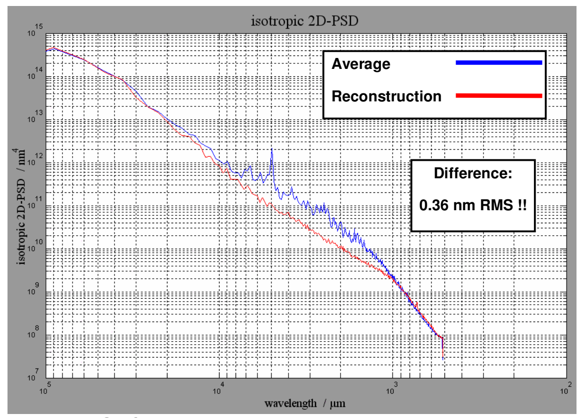

Fig 7: *PSD´s Averaging/Reconstruction Method*

Obviously, Averaging introduces additional noise in respect of Reconstruction. The quantitative noise level is obtained by integrating the difference of both PSD-plots. But we have to take into account, that the k*N_α-waviness of the test surface is missing in the reconstruction result (see fig. 5). Assuming monotonous performance of the azimuthal spectrum of the test surface, we can give an estimate for the k*16-waviness by taking the average of k*15 and k*17-waviness. After appropriate correction of the PSD integral, we end up with a noise of 0.34 nm RMS, which is only caused by the Averaging Method !

5 Conclusions

In contrast to the Averaging Method, the Reconstruction Method neither adds interpolation noise, nor shearing artefacts, because any re-sampling of data maps is avoided.

The requirements concerning the drift stability of the interferometer are much lower for the Reconstruction Method, because the interferometer drift is subtracted off instantaneously by taking the difference of zero-degree and angular measurement. Therefore, the selection of N_α is no longer limited by the drift of the interferometer error. This allows to increase N_α and therefore an increase of the spatial bandwidth of the test surface measurement.