Analysis of polishing errors from subaperture tools

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The polishing process of aspheric or freeform surfaces is normally implemented as a subaperture process with controlled movement of the tool. The use of different tools and controlling mechanisms may introduce errors. The errors related to the shape and the size of the tools and the influence of optimization algorithms is compared by using the 'Power Spectral Density' (PSD).

1 Introduction

In the traditional polishing of aspheric surfaces subaperture tools are moved over the surface with an optimized dwell time profile in order to eliminate subsurface damage (SSD) and correct remaining surface errors introduced by the preceding processes.

The dwell time profile t_{dwell} can be calculated by solving a set of linear equations, with A_{wear} being the wear functions of the tool and $S_{removal}$ the desired wear on the surface.

$$A_{wear} \cdot t_{dwell} = S_{removal} \quad (1)$$

The wear functions of the tool can be generated e.g. by measurement of the wear of a real tool or by simulation [1].

Solving (1) requires a set of basic conditions e.g. the dwell time has to be positive or the dynamic between two nearby points is limited. Implementing these constraints leads to algorithms that approximate the best solution.

Taking the shape and size of the wear functions into account the correction properties of a given tool are limited. So after the polishing process residual errors will remain on the surface.

The analysis of those errors can be done by calculating the power spectral density (PSD). This method is able to show the correction properties of a tool in relation to the wavelength of the errors on a surface [2].

2 Tool geometry

The model to describe the characteristics of the elastic tool is described elsewhere [1]. Different tools were simulated by changing the induced force on the polishing tool. Fig. 1 shows the simulation results. The width of the tool (FWHM) varies between 9.4mm for 40N and 3.3mm for 5N.

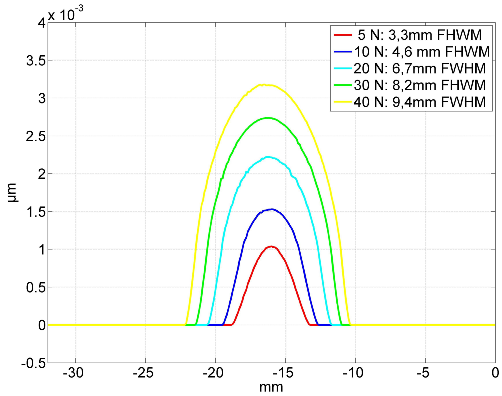

Fig. 1 wear functions in relation to induced force at position x=-16mm

3 Simulation and Optimization

The wear functions were calculated on an aspheric surface with a maximum deviation from the best fit sphere of about 0.9 mm. The diameter was 64mm.

The input parameter for (1), the artificial wear $S_{removal}$ was generated including critical spatial frequencies and a small part of constant wear. This set of equations was solved using two different algorithms to get the best dwell time profile for the given equations. The result of the two optimizations is shown in Fig. 2.

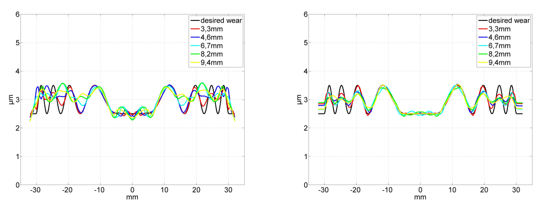

Fig. 2 optimized wear using two different algorithms

While the optimization errors on the right picture in the central zone from x=-5..5 mm are relatively low, the algorithm producing the left picture introduces additional surface errors.

Another difference is seen in the area between x=15..30 mm; while the left algorithm produces dissatisfying results for the 4.6 to 9.3 mm wear functions, the wear in the right algorithm in Fig. 2 shows similar characteristics as the desired wear.

Looking at the difference between the simulation results and the desired wear the remaining errors have different behaviours. While at Fig. 3 at the right side the error shape between x= 15..30 mm is almost identical for all wear functions, the shape at the left side varies strongly with the wear function. Those additional shape errors can be seen in Fig. 2 as shape variations between simulated wear and desired wear

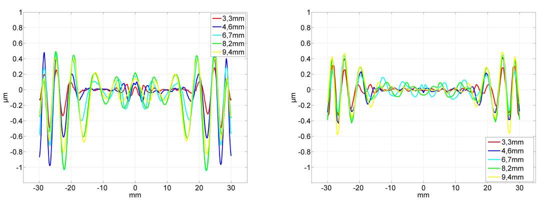

Fig. 3 Remaining error of two different algorithms

Converting the spatial domain data of Fig. 3 to the frequency domain, the Power Spectral density (PSD) can be calculated. It is defined as the Fourier Transform of the auto-correlation function and shows the spectral distribution of the data. In this case the PSD can be understood as an indication of the correction abilities of a tool in relation to the wavelength of the error.

The wear function with 9.4 mm FWHM is able to reduce the spectral components at the left plot down to a wavelength of 7.3 mm as can be seen in Fig. 4. In contrast the right plot indicates a correction depth down to 5.9 mm for this algorithm.

Between 7.3 mm and 5mm, the PSD on the left side even increases above the level of the desired wear and adds additional errors in this range. Only the smallest wear function is able to reduce the error on the left side down to a wavelength of 3.2 mm.

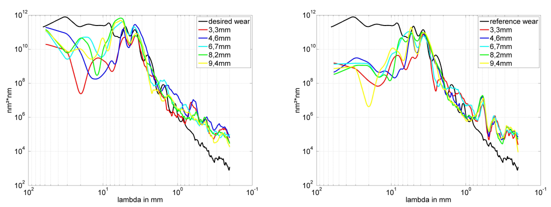

Fig. 4 PSD of remaining error of two algorithms

The increase below 1 mm wavelength in Fig. 4 is a simulation artefact and isn't seen in the real polishing process.

Assuming that the error correction ability of a wear function goes down to the highest wavelength in Fig. 4 that is lower than the PSD of the desired wear leads to Fig. 5. It shows the correction abilities depending on the FWHM of the wear function.

The influence of the optimization algorithm is visible but in this case limited to the larger wear functions.

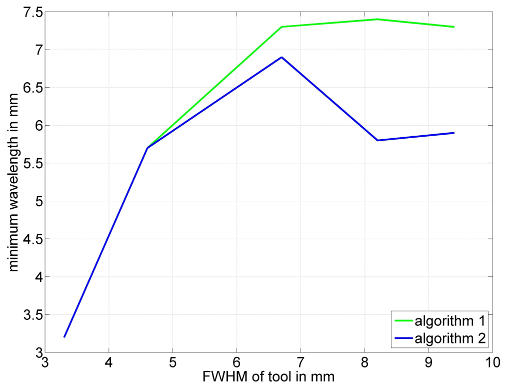

Fig. 5 minimum correctable wavelengths in relation to the FWHM of the tool

4 Conclusion

It is demonstrated that not only the width of the wear function has an influence on surface waviness which can be corrected; the applied algorithm is also of importance. With both optimization algorithms it is possible to correct surface errors down to a wavelength of 3.2 mm, which is approximately the FWHM of the tool. Knowing the PSD of the surface errors to be corrected the best tool parameters can be selected easily.

References

[1] A. Kelm, R.Boerret, S. Sinzinger: „ *Modeling of the polishing process for aspheric optics* " *SPIE Proceedings Vol 7102, 2008*

[2] *R. Boerret, A. Kelm, H. Thiess, :"High-speed form preserving polishing of precision aspheres", SPIE Proceedings Vol 6671, 2007*