Method to evaluate the impact of geometrical turning factors on optical power accuracy of ophthalmic lenses

L. R. Castro Martinez, B. Fermigier
Essilor International - R&D - France
castrol@essilor.fr, fermigib@essilor.fr

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Abstract

The latest generations of progressive lenses to correct presbyopia are individually optimized to take into account more and more personalized physiological and behavioural parameters, ensuring the best optical function for each wearer. These lenses composed of at least one non rotational surface, sometimes called free form surface. This complex geometry is digitally surfaced for each individual lens using two main process steps: fast-tool diamond turning and fine polishing.

1. Introduction

The fast-tool diamond turning of ophthalmic lenses is a specific process. The theoretical surfaces could be spheres, torus or free form with a very large range of curvatures and diameters. One important particularity of the fast-tool diamond turning is that each surface interacts differently with the sources of geometrical error. This study describes a method to evaluate the impact of the principal sources of geometrical error on optical quality.

The method consists of four steps: experimental misalignment evaluation, tool wear measurement, geometrical turning simulation and simulated surface analysis. Four factors were studied simultaneously: two machine axis misalignments, the tool calibration gap and the tool radius evolution caused by wear. The cutting geometrical model and the software for simulation and surface analysis were developed for this study. Finally, the simulation was compared to the experimental results.

2. Measurement of geometrical errors

2.1 Evaluation of machine axis misalignments

The machine kinematics is schematized in Fig. 1. The spindle rotates around the C-axis and moves along the X-axis. The tool is mounted on a fast tool (FT), it slides along Z-axis and theoretically must be aligned with the C-axis. Two misalignments were chosen to be simulated. The first one is the perpendicularity between the X-slide and the spindle-axis and the second one is the parallelism between the spindle and the fast tool axis.

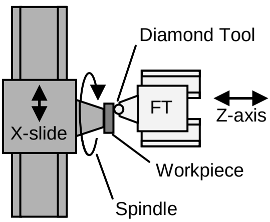

Figure 1: Schematic diagram of the machine.

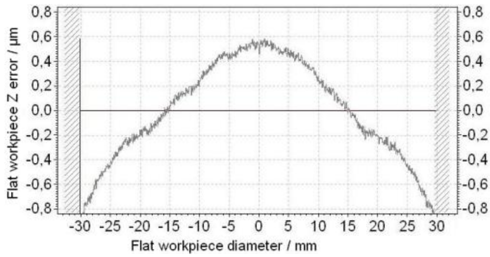

Figure 2: Perpendicularity diamond turning evaluation using a flat workpiece.

The misalignment evaluation is carried out by an indirect way measuring aluminium workpieces. The perpendicularity is evaluated by means of one flat piece and the parallelism is evaluated with two spherical pieces with the same radius but at different thicknesses (two Z coordinates). Fig. 2 shows the Z error of the workpiece measurement. The perpendicularity signature is a conical surface (1.4 µm / 30 mm). The X-slide straightness error [1] is insignificant regarding the perpendicularity.

2.2 Evaluation of geometrical tool wear

To evaluate the geometrical evolution of the worn tool, the cutting edge is measured using a microscope. After that, the cutting edge coordinates are fitted using a polynomial. Fig. 3 shows the difference between the worn tool measurement and the tool reference radius specified by the supplier.

2.3 Evaluation of X-slide setting error

The X-slide setting error (gap between the tool centre and the C-axis on the X-slide direction) has a strong impact on the lens power in the centre. To avoid this problem, the setting tolerance is close to 10µm. Nevertheless, the control method of the X-slide setting is quite sensitive and it could interact with other mentioned sources.

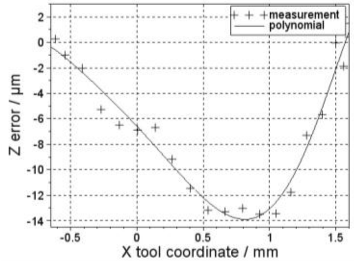

Figure 3: Tool wear evaluation (measurement points and fitted wear profile).

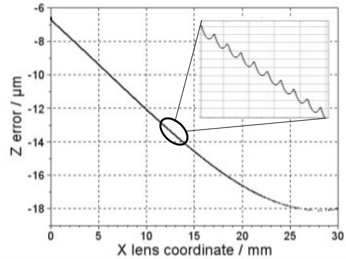

Figure 4: Example of simulation results.

3. Simulation

3.1 Model

The model permits to simulate the workpiece surface obtained by turning. The reference tool path is established by the cutting parameters: workpiece radius (mm), new tool radius (mm) and feed (mm/revolution). The model takes into account the four sources of error simultaneously (perpendicularity, parallelism, tool wear and X-slide setting). The model does not take into account the dynamic error [2].

3.2 Results

The output of model simulation is the surface and its error regarding the reference surface. Fig. 4 shows an example of simulation including the four error source evaluations.

3.3 Analysis

To evaluate the surface power error, the local curvature is calculated using block-sizes. The surfaces can be obtained by measurement or simulation (real or virtual surfaces). The whole surface is analyzed block by block. It is necessary to note that the power values depend on analysis parameters (block-size length and block sampling step). Fig. 5 shows the analysis of simulations for the four error sources (misalignments, worn tool and X-slide setting error) and several surface radii. The most critical point of all surfaces is the centre at X = 0 mm and the most critical surface radius is 65 mm.

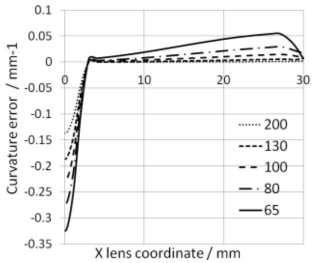

Figure 5: Surface power analysis for several surface radii (65 mm to 200 mm).

4. Experimental results

Cutting tests and simulations were performed with two X-slide setting errors -50 µm and +50 µm. The results validate the model as can be seen in Fig. 6.

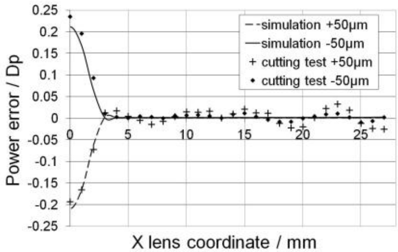

Figure 6: X-slide setting error, cutting tests vs. simulation (surface radius = 100 mm).

5. Conclusions

A model for simulating four geometrical sources of error in turning (perpendicularity, parallelism, tool wear and X-slide setting) was developed and validated experimentally. A calculation tool to analyse the surface power was developed. The amplitude of the power error is impacted significantly by the four sources of error and it also depends on the workpiece radius. The X-slide setting is the most critical source of error regarding the performed evaluations.

References:

[1] Gao W, Tano M, Araki T, Kiyono S, Hong Park C, *Precision Engineering*, Vol. 31 p.310-316 (2007)

[2] Yu D P, Soon Hong G, San Wong Y, *International Journal of Machines Tools and Manufacture*, Vol.52, p.13-23 (2012)