Smoothing Effect Analysis for Active Fluid Jet Polishing

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Abstract: Analysis of optical surface smoothing effect using Active Fluid Jet Polishing (AFJP) is presented. High speed AFJP process with overlapping tool motion produces smooth optical surfaces.

1. Introduction

Computer Controlled Optical Surfacing (CCOS) is a highly efficient process for the fabrication of precision to ultra-precision optical surfaces. In CCOS a subaperture tool (relative to workpiece surface) meanders over the entire surface in a predefined path. Depending upon the processing technology and process parameters, sub-aperture polishing produces residual signatures in mid-spatial frequency regime [1-3]. Fluid jet polishing [4] uses fine jet polishing fluid striking against the workpiece surface. However, due to fluid bombardment the Tool Influence Function (TIF) is not stable in the fluid jet polishing process. The Active Fluid Jet Polishing (AFJP) is a sub-aperture corrective polishing process (applied to various complex optical surfaces). The polishing process using AFJP is based on indirect fluid jet polishing, where a cylindrical pin with a polishing matrix on the front tip is placed inside a cylindrical cavity in the polishing nozzle. Pressurized fluid is feed from the cavity behind the cylindrical tip generating constant pressure. This fluid presses the cylindrical tip against the glass surface. Fluid comes out from the annular spacing around the cylindrical polishing tip during the tool rotation. The polishing tool is rotated at high speed about the rotation axis. This creates eccentric motion of the polishing spot. Eccentric motion helps in removing surface errors efficiently using overlapping effect of tool motion. Schematic representation of the AFJP process along with material removal contour, instantaneous depth removal rate, instantaneous pressure and instantaneous relative velocity is shown in Figure 1.

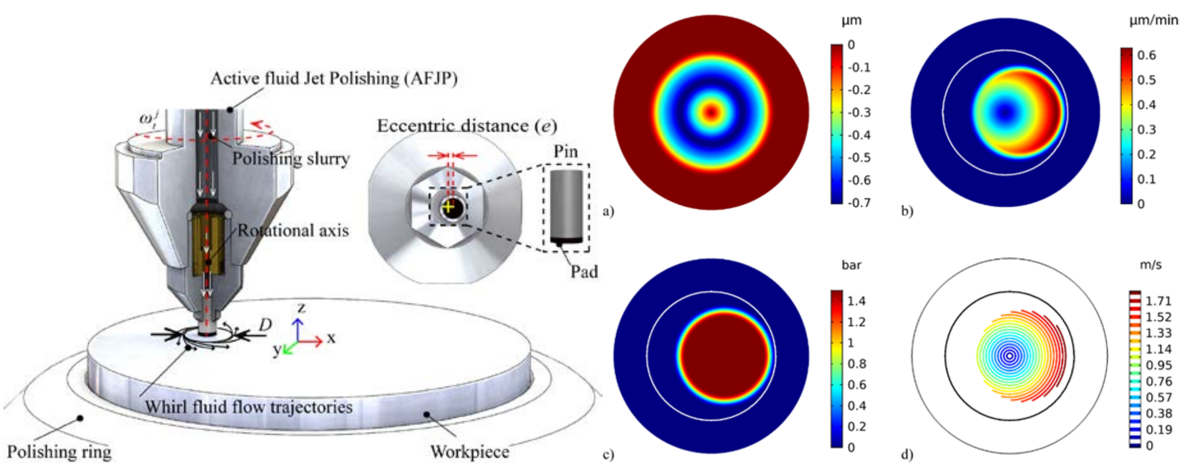

Fig. 1. AFJP tool rotating at angular velocity $\omega_t{}^j$ flow passage of polishing slurry polishing pin with eccentre *e*, creating a spot of diameter *D*. Static TIF analysis of AFJP (OptoTech) at 1.5 bar with pin radius R_{pin} 5 mm, *e* 2 mm, tool rpm N_t 2000 rpm and dwell time 120 s showing a) material removal map, b) instantaneous depth removal rate, c) instantaneous contact pressure distribution and d) instantaneous relative velocity distribution.

2. Tool Influence Functions of AFJP

The static TIF of AFJP is symmetric about tool axis because the fluid loading on pin due to fluid pressure from back of pin produces constant pressure during intimate contact between tool and workpiece. The contact pressure distribution and relative contact velocity is shown in Figure 1 c) and Figure 1 d), respectively. AFJP depth removal rate is very low as compared with the Flexible Membrane Polishing processes [5]. The material removal map and DRR (Depth Removal Rate) of AFJP polishing tool is shown in Figure 1 a) and Figure 1 b).

Dynamic footprint analysis was carried by traversing tool along the line using different pin radius R_{pin} 5 mm, and by considering edge relief equivalent to the spot radius on both left and right size for reference as shown in Figure 2. The footprints in Figure 2 (Left) shows the material removal depth with different operating tool pressure p_o 1, 1.25 and 1.5 bar operated at 1500 rpm for 900 s. AFJP dynamic footprint produces a characteristic W-shaped cross-section profile (due to its orbital tool motion) normal to the tool path direction.

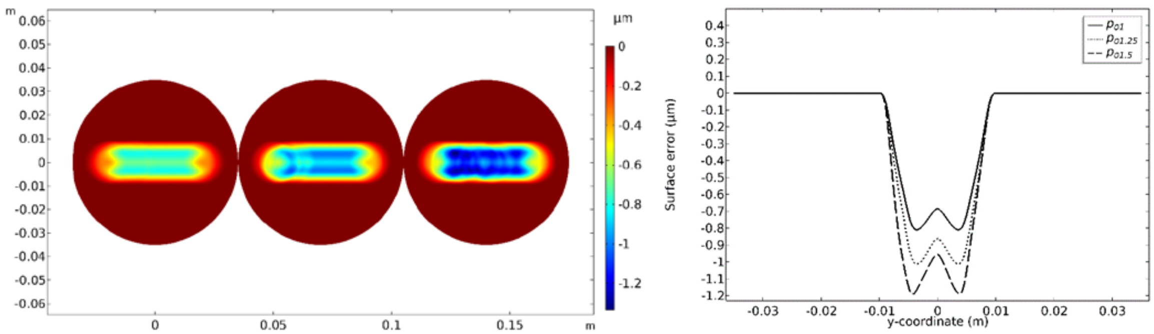

Fig. 2. AFJP removal footprints for R_{pin} 5 mm, p_o 1, 1.25 and 1.5 bar operated at 1500 rpm for 900s (left) and 2-dimensional section profile of the polished zone (right).

3. Experimental Results and Conclusion

Figure 3 shows the comparison of surface texture produced at different fraction of raster tool path spacing (*frac*) and its graph showing the change in *rms* (in nm) with different *frac* during the AFJP polishing process.

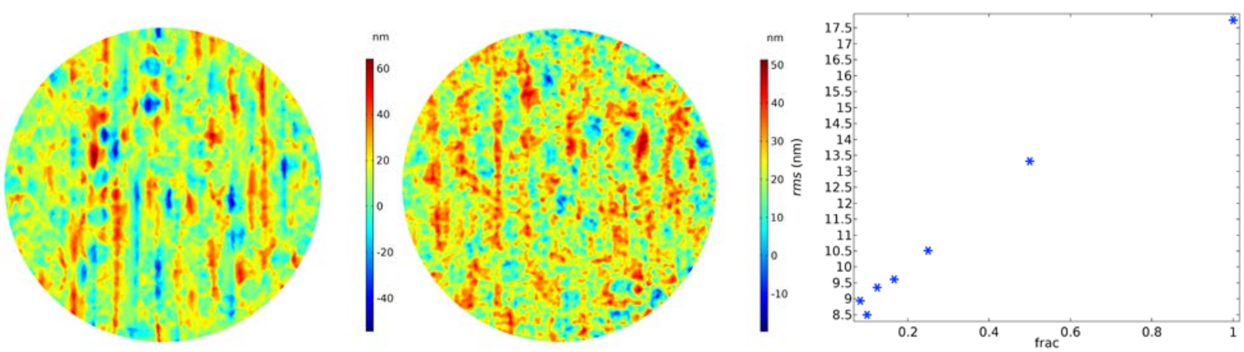

Fig. 3. Surface error maps after AFJP process using R_{pin} = 3 mm, e = 1.5 mm and N_t = 1500 rpm, on 150 mm diameter workpiece. The raster path spacing was $(R_{pin}+e)\times frac$, where *frac* is the fraction of effective spot radius $R_{pin}+e$. Two surface error maps for *frac* = 0.5 (left) and *frac* =1/12 (center) cases show the polished surface quality. The *rms* values as a function of *frac* (1, 1/2, 1/4, 1/6, 1/8, 1/10 and 1/12) are plotted (right).

It can be concluded from the analysis that the *rms* gets smaller for smaller tool path raster spacing (i.e., $frac\times(R_{pin}+e)$), which produces more isotropic surface texture due to the increased overlapping effect of AFJP tool motion.

3. References

[1] Javier Del Hoyo, Heejoo Choi, James H. Burge, Geon-Hee Kim, and Dae Wook Kim, "Experimental power spectral density analysis for mid- to high-spatial frequency surface error control," Appl. Opt. 56, 5258-5267 (2017)

[2] R. J. Noll, "Effect of mid- and high-spatial frequencies on optical performance," Opt. Eng. 18(2), 182137 (1979).

[3] D. M. Aikens, J. E. DeGroote, and R. N. Youngworth, "Specification and Control of Mid-Spatial Frequency Wavefront Errors in Optical Systems," in Frontiers in Optics 2008/Laser Science XXIV/Plasmonics and Metamaterials/Optical Fabrication and Testing, OSA Technical Digest (CD) (Optical Society of America, 2008), paper OTuA1.

[4] Oliver W. Fähnle, Hedser van Brug, and Hans J. Frankena, "Fluid jet polishing of optical surfaces," Appl. Opt. 37, 6771-6773 (1998).

[5] Vipender Singh Negi, Harry Garg, Shravan Kumar RR, Vinod Karar, Umesh Kumar Tiwari, and Dae Wook Kim, "Parametric removal rate survey study and numerical modeling for deterministic optics manufacturing," Opt. Express 28, 26733-26749 (2020)