Super Smooth Finishing of Optical Surfaces By Fluid Jet and Bonnet Polishing

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Abstract: Fluid jet and bonnet polishing are processes deployable on a common 7-axis CNC machine. Using them in combination, it is possible to achieve 31nm P-V form accuracy and 0.3nm rms surface roughness on freeform optics.

Keywords: optical finishing, corrective polishing, fluid jet polishing, bonnet polishing

1. Introduction

Ultra-precision diamond turning [1] or grinding [2] can be used to produce complex optical surfaces such as aspheres and freeforms. But the magnitude of form error and surface roughness tends to vary with the complexity and size of the workpiece. In most cases, a post-finishing process is required to smooth the surface roughness and improve the form accuracy. In this paper, two finishing technologies called Fluid Jet and Bonnet Polishing are presented (see Fig. 1). They are deployed on a common 7-axis CNC machine, and can be used in combination to achieve form error less than 31nm P-V ($\lambda/20$) and surface roughness less than 0.3nm rms.

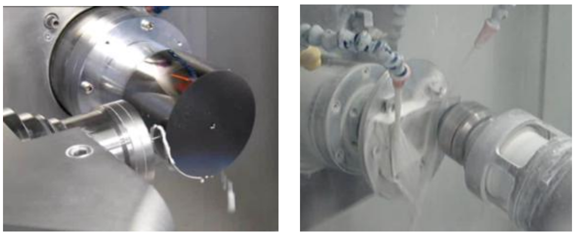

Fig.1. Fluid Jet and Bonnet Polishing on common 7-axis CNC machine

2. Fluid jet polishing

The fluid jet polishing (FJP) process consists of pressurized water and abrasive particles mixed and delivered through a nozzle [3]. Typical operating pressures range from 4 to 20bar, nozzle size from 0.1 to 2.0mm, and abrasives from 0.1 to 100um. The process has been recently optimized with a newly designed slurry delivery system (see Fig. 2) including a pressure feedback loop and adjustable bypass valve for regulating flow rate through the system.

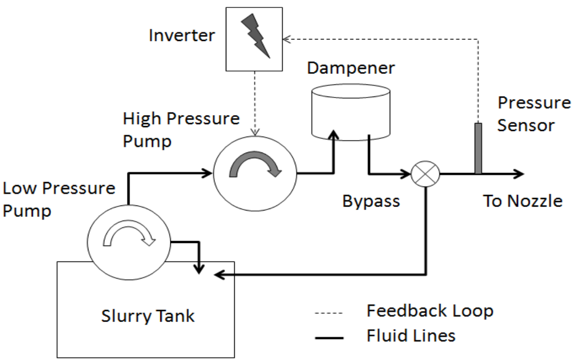

Fig.2. Diagram of slurry delivery system to FJP nozzle

A series of experiments were conducted on electroless nickel plated samples, to assess removal rate and surface texture dependency on certain process parameters such as abrasives size (2um and 4um alumina) and fluid pressure (see Fig. 3).

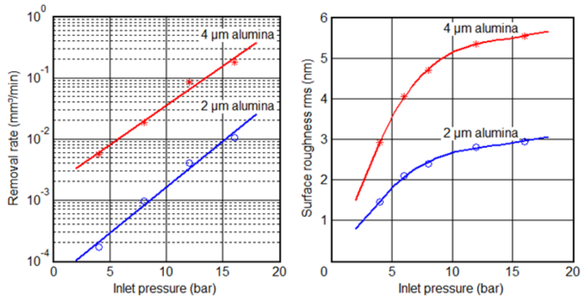

Fig.3. Removal rate and surface roughness of fluid jet polishing as function of abrasive size and inlet pressure.

By presenting the data with a log scale in the Y-axis direction, it is possible to visualize the removal rates increase as an exponential relationship of inlet pressure. This type of progression holds true for the two different grit sizes used in the experiments. Such high rate of change in removal rates is desirable, since the process speed can be scaled up or down depending on the magnitude of form error to be corrected and the maximum physical feeds usable on the linear and rotary axes of the CNC machine. According to the surface roughness plots, it is also possible to improve surface texture by polishing with progressively lower inlet pressure and grit size for each pass.

3. Bonnet polishing

Precessed bonnet polishing is a sub-aperture finishing process which has been described in the literature at various stages during its development [4,5]. The operation of the process is shown in Fig. 4 (left): The position and orientation (precession angle) of a spinning, inflated, membrane-tool are actively controlled as it traverses the surface of a workpiece. The workpiece may have any general shape, including concave, flat, or convex, aspheric or free-form.
But rather than just rely on the usual “single precess” polishing regime described in previous literature, whereby the tool is precessed in a given direction for each polishing pass, a novel tool path control method called “continuous precessing” is introduced. In this

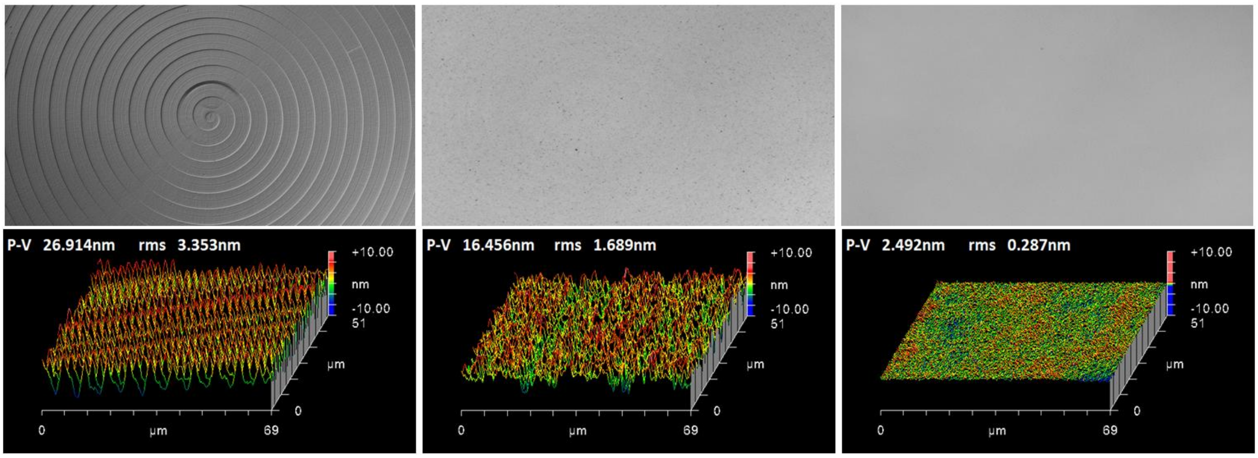

Fig.7. Roughness after diamond turning (left), fluid jet polishing (centre), and continuous precess polishing (right).

method, shown in Fig. 4 (right), the direction of the surface tangent used to compute the plane of precession of the spherical tool is allowed to spin around the centre of the polishing spot.

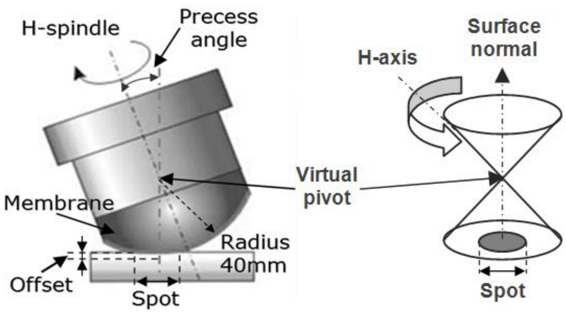

Fig.4. Principle of Bonnet Polishing Tool (left) and Continuous Precessing Motion (right)

This motion may be compared to the wobbling of a spinning top, or the progressive change in the rotation axis of the earth: in those two examples the rotation axis describes a cone. In a similar way, the H-axis describes a cone around the polishing spot, thereby allowing the polishing direction to change continuously as shown in Fig. 5 (bottom).

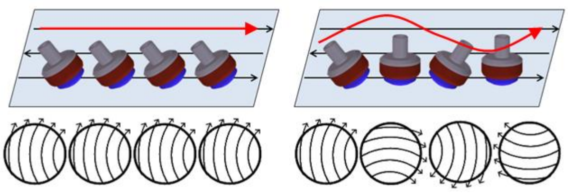

Fig.5. Single (left) and continuous precessing (right) across raster tool path, and polishing direction (bottom).

4. Corrective polishing

Corrective polishing software can be used with both processes. Influence functions are generated on a piece of similar material and curvature, and used to optimise the polishing spot feed rates across the workpiece. An example of form correction is shown in Fig. 6, where a 150x150mm workpiece was improved from a form error of 610nm P-V down to 41nm P-V in 2 iterations.

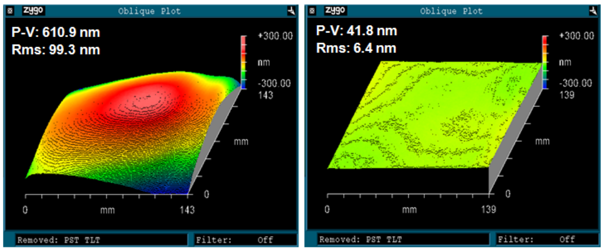

Fig.6. Corrective polishing of 150x150mm workpiece.

5. Conclusions

Fluid Jet and Bonnet Polishing have been presented, which are deployed on a common 7-axis CNC machine capable of freeform polishing. The FJP process can effectively remove diamond turning marks (see Fig.7 centre) and features removal rates spanning several orders of magnitude depending on inlet pressure and grit size. The bonnet polishing process can be controlled to continuously change the polishing direction, and thus achieve super-smooth roughness below 0.3nm rms (see Fig. 7 right). Both processes can correctively polish form error down to 31nm P-V.

6. References

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