Finishing of Optical Materials Using Fluid Jet Polishing

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Abstract

The characteristics of Fluid Jet Polishing (FJP), a newcomer in the field of optical fabrication, or more specifically optical finishing, are presented. Comments on the process possibilities are given, e.g. spot shape, process speed, and parameter dependencies. Preliminary results on a wide range of materials are discussed.

1 Introduction

The shaping and finishing of steep, concave sections of a-spheres, e.g. conformal optics, in brittle materials such as glass represent a challenge for optical fabrication research. Aspheres are usually finished applying sub-aperture-polishing methods moving a small polishing tool over the surface to be generated, requiring an accurate computer control. The applied finishing techniques can be e.g. CCP (computer controlled polishing) or MRF (MagnetoRheological finishing). Besides, using ion beams, the aspherical surface can be generated by shaping a previously finished spherical surface without increasing its surface roughness.

It is known to be possible to cut glass by the use of Abrasive Slurry Jets (ASJ) where a stream of premixed slurry is entrained and guided to the surface by the use of a nozzle. ASJ systems operate at pressures above 70 bar (typically several hundreds of bars).

It was our idea to employ an ASJ system at very low pressures to finish optical surfaces, and that it can then be used to reproduce the aqua planing effect as observed in bowl feed polishing. Bowl feed polishing is known for its very good results on flat surfaces. FJP is thus expected to be capable of bringing the results of bowl feed polishing to the production of steep aspherical surfaces.

This paper will first briefly discuss our experimental FJP system after which the experiments and their results will be highlighted. Finally the discussion will go into the possibilities of the presented method.

[#] The presented work was carried out while Oliver Fähnle was with DeCOS, Delft Center for Optical Surfaces, TNO Institute of Applied Physics, Delft, the Netherlands

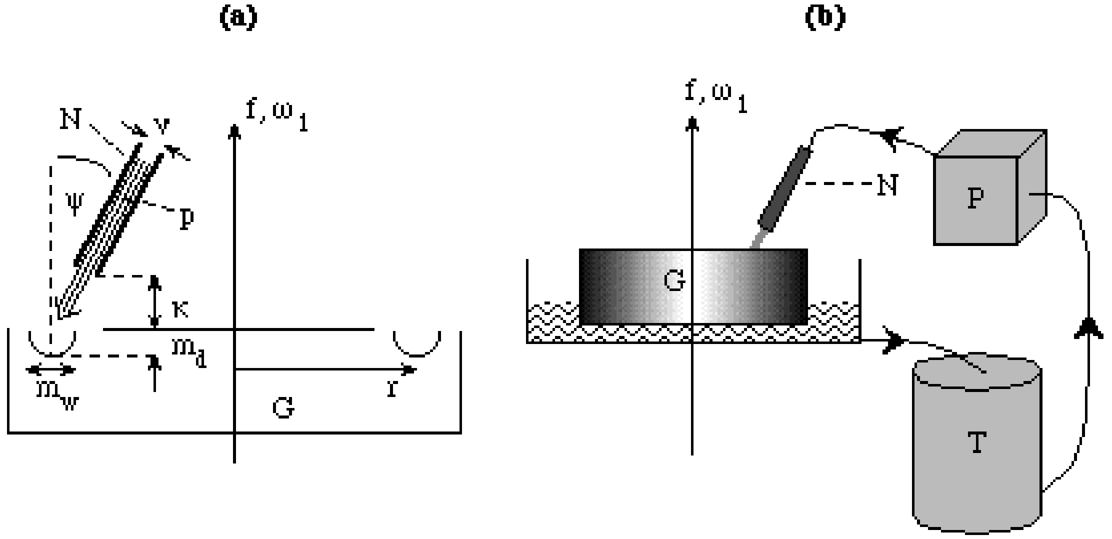

Figure 1 Schematic diagram of the experimental set-up used to demonstrate the finishing process of Fluid Jet Polishing (FJP). (a) Diagram showing the relative position of the nozzle N with respect to the work-piece G and defining the parameters. (b) Diagram of the closed loop set-up comprising the tank T containing the slurry, the pump P and the nozzle N that is positioned above a lapping machine.

2 Fluid Jet Polishing

The FJP process has already been described in literature[1,2,3] and will here only briefly be touched upon. A plastic tank T (see Fig. 1) is used to mix water and a grinding and/or polishing compound. This can be done either by mechanical stirring or by blowing air through the mixture. The water with the homogeneously mixed particles in it is referred to as the slurry. This slurry is pumped from the tank by means of a low-pressure pump P and guided through a nozzle N. Typically, the pressure values range from 0 up to 15 bar. The nozzle is positioned above the surface G being processed where the stand-off distance and the angle with respect to the surface normal can be chosen. After processing the surface, the slurry is collected and guided back to the tank for reuse.

The stand-off distance is typically in the order of some millimeters and the diameter of the cylindrical nozzle in the here described experiments was 0.84 mm. Other nozzles have also been utilized, cylindrical nozzles having other diameter as well as differently shaped nozzles. The closed loop design is found to work to our satisfaction. No degradation of the processing is observed, even after 20 hours of using the same slurry. The process is found to be independent of the stand-off distance (1 mm up to 10 cm) as long as no air is mixed within the slurry jet. The processing spot was found to be about 3 times the size of the nozzle diameter.

A typical concentration of the particle contents in the slurry is 5% to 10%. Used particles are Cerium Oxide (polishing compound) and #800 and #1200 Silicon Carbide (grinding compounds).

3 Results

We applied the FJP process to several different types of materials, i.e. glass, amorphous (BK7) as well as crystalline (silicon, ruby and sapphire), metals, and plastics. For all materials it was found that the surface shape could be altered, and that the roughness could be reduced. The material removal speed depends on the pressure within the FJP system and on the particles (concentration and type). Material removal of 1.5 µm in one hour was observed for polished sapphire while for softer materials, e.g. BK7 or aluminum, a removal as high as 40 µm or higher was found. These values were obtained with a pressure of 10 bar and an angle between the nozzle axis and the surface normal of 45 degrees.

To what extend the surface roughness could be reduced was found to depend on the initial surface roughness and on the surface hardness. For polished surfaces no surface degradation was observed due to the FJP processing. For ground surfaces it was found that the roughness could be improved by at least an order of magnitude in the case of BK7 and all of the metals. For the ground crystalline materials, sapphire and ruby, the improvement on the roughness was less significant, about 10 – 20%. The processing was performed with 10% #800 SiC particles in the case of the BK7 and the metal samples. For the crystalline samples the slurry contained 5% of #1200 SiC particles and 5% of cerium oxide.

4 Discussion

Although it was mentioned in the abstract that FJP is specifically suited for optical finishing, it has to be noted that it can also be applied for shaping purposes. As mentioned within Section 3, it is possible to shape a smooth, polished sample, without degrading its roughness. This makes FJP well suited for shape corrections after the surface has been finished and characterized.

Tentatively, we can explain the process of FJP as follows. The particles, present in the jet, are guided to the surface where the jet is redirected due to the collision with the surface. The particles, due to their higher density than water, are assumed to be forced to the outer-side of the fluid beam where they come in contact with the surface.

In our opinion, the interaction of the particles with the surface is dictated mainly by a few quantities, i.e. among others, the size and shape of the particles, the surface roughness and the surface hardness. For surfaces with a low hardness, e.g. plastics and some metals, the process is found to be ductile, while for high hardness materials, e.g. ruby and sapphire, the process will be brittle.

As soon as the surface roughness is smaller than several tens of nanometers, the material removal is always in a ductile manner. This is believed to be the case as soon as there are no chunks of material sticking out above the surface, which of course is the case for a polished surface. For these smooth surfaces, the particles in the fluid beam will no longer collide with protruding parts, and hence will only shear across the surface. Due to the shear force, material is removed in a ductile manner.

Experiments using different types of nozzle shapes have shown one the most powerful features of FJP. For cylindrical nozzles, i.e. nozzles with a circular cross section, the processing spot is found to be w-shaped for normal incidence operation, and to shift to a more u-shaped halo type of spot for increased angles between the nozzle and the surface normal. The ratio between spot size and the nozzle diameter was always found to be about three, independent of the stand-off distance, provided that no air was mixed into the fluid jet. By changing the nozzle cross-section, the processing spot can be altered. We started an investigation on the use of rectangularly shaped nozzles and found that these types of nozzle are promising candidates for fast finishing of larger areas, owing to their homogeneous operation.

Owing to the processing method, FJP can be used for the finishing and correcting of conformal optics. Steep concave parts of conformal mirrors are a challenge for the optical industry since the presently standard methods of polishing are not applicable in these areas. Since the tool in the case of FJP is only a small nozzle that can easily be reshaped if required, FJP can be used even in the case of steep concave surfaces.

5 Conclusions

We have discussed the fluid jet polishing process and pointed out what its capabilities are. It has been shown that it can be used for the finishing of optical surfaces, as well as for shaping. In general it can be stated that the roughness of a surface will not be degraded due to an FJP shaping process and in many cases it is found that the roughness even improves. It has been pointed out that FJP is one of the enabling technologies for the production of conformal optics.

References

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