Removal of diamond-turning signatures on x-ray mandrels and metal optics by fluid-jet polishing

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ABSTRACT

This paper describes a major advance in the post-treatment of diamond-turned surfaces to remove repetitive micro-structure; a result which could have a major beneficial impact on fabrication of Walter-type X-ray mandrels, and metal mirrors. Diamond-turning is highly deterministic and versatile in producing axially-symmetric forms, and through fast-tool servos, non-axially symmetric, free-form and micro-structured surfaces. However, the fine turning marks left in the metal surface limit performance. In this paper, we describe how fluid-jet polishing under CNC control can be used to eliminate these structures, without significantly degrading the surface roughness or form produced by the prior turning operation.

Keywords: Polish, diamond-turn, texture

1. INTRODUCTION

Single-point diamond-turning is well-established as a method to create precise axially-symmetric forms on ductile materials, including flats, spheres, aspheres and cylindrical forms. With the addition of a fast-tool servo operating in a phase-locked loop, non axially-symmetric forms can also be produced. A typical example is the production of large off-axis aspheric mirrors for the three-mirror astigmatic configuration.[1] Other applications include various infrared mirrors, and mandrels for producing the cylindrical forms of Walter-type X-ray mirrors. The main limitation has been the resulting micro-structure which is cyclic in nature ('turning marks') and which produces diffraction effects and stray light. For this reason, X-ray mandrels in particular are post-polished to achieve both the form and texture required.

Chon et.al [2] have described their work on replication-mandrels for Walter Type 1 mirrors used in soft X-ray microscopy. Their master mandrels were produced by single-point diamond turning, but required hand post-polishing to remove the high spatial frequencies on the surface. As they pointed out, this is extremely difficult on aspheres, and leads to an inevitable tradeoff between quality of the surface texture achieved and destruction of the aspheric figure. Clearly a method to remove the diamond-turning signature without destroying form could be an important step forward.

Fluid-jet polishing (FJP) is a method in which a slurry of polishing particles is pressurized and projected through a jet towards the surface to be polished. The jet impacts the surface of the part directly, i.e. with no physical tool. Booij et.al.[3] have shown the linear dependence of removal rate with slurry concentration. They also show the non-linear dependence with impact-velocity, due to the combined effects of i) a minimum velocity-threshold below which no removal occurs, ii) the increased rate of particle-delivery with increased velocity and iii) the square relation between particle kinetic energy and velocity. They conclude that, using appropriate abrasive and particle size with the right flow velocity, FJP can achieve ductile-regime removal with stable volumetric removal-rate. L. Yang, Y.Chen, E-B. Kley and R. Li have also investigated fluid jet polishing and have concluded [4] that the removal process is a mixture of shear and collision mechanisms. They particularly drew attention to the constancy of the removal function as the jet overhangs the edge of the part, asserting that, to some extent, the FJP edge-effect can be neglected in small tool polishing.

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Zeeko Ltd has implemented fluid jet polishing as an option on its family of polishing machines, to complement the Zeeko Classic [5, 6] and Zeeko Grolish [7] processes. In the work reported in this paper, the Zeeko-Jet process has been used to attenuate diamond-turning marks on electroless nickel coated samples. This potentially opens up new applications for diamond-turned surfaces, as well as improving performance in current applications.

2. EXPERIMENTAL RESULTS

2.1 Flat sample

Figure 1 Flat sample

A 100mm diameter diamond-turned electroless-nickel plated plano mirror (Figure 1) was used for the experiments reported here. The surface texture (Figure 2) was first measured using an ADE MicroXam Interferometer resulting in Ra = 3.2nm.

The surface was then fluid-jet polished on the Zeeko IRP200 machine using Rhodia 1663 cerium oxide slurry at a pressure of 20 bar, resulting in the texture shown in Figure 3 and an average surface roughness of Ra=2.8nm. This eliminated the mid spatial frequencies from diamond-turning, substituting a randomized micro-structure. This is confirmed by Power Spectral Density results (Figures 4, 5).

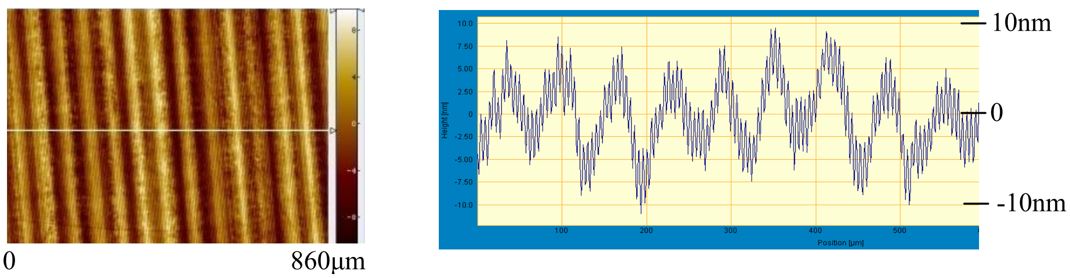

Figure 2 Texture of diamond turned electroless-nickel surface before fluid-jet polishing

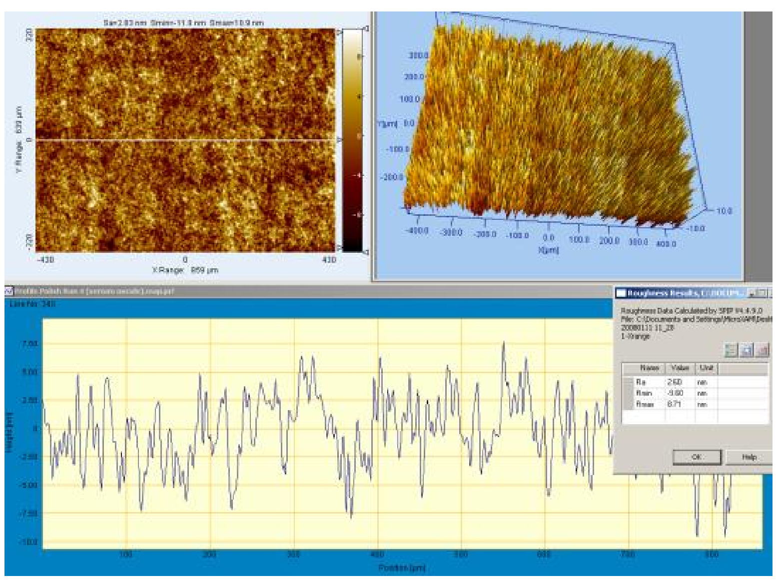

Figure 3 Texture of diamond turned electroless-nickel surface after fluid-jet polishing

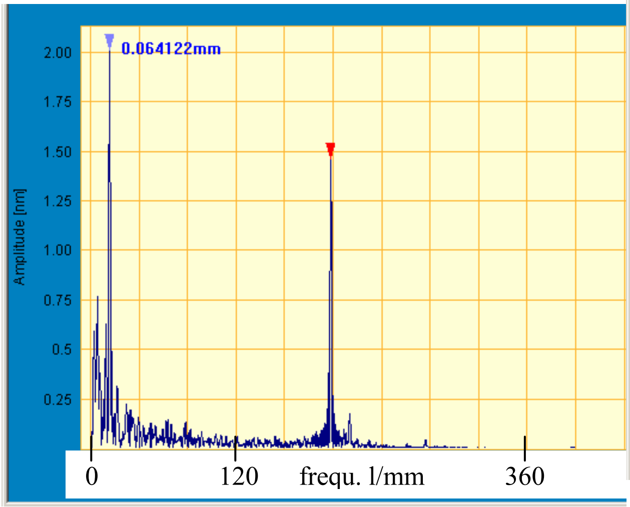

Figure 4 PSD of diamond-turned plano surface

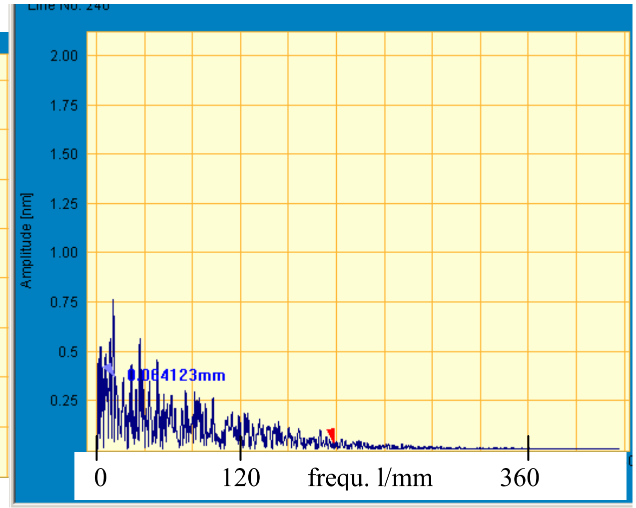

Figure 5 PSD of fluid-jet polished diamond-turned surface

2.2 Aspheric sample

The sample was an electroless-nickel coated mirror 8.55mm diameter that had been diamond-turned to an asphere. The form of the diamond-turned surface was measured using a Taylor Hobson PGI Form Talysurf stylus profilometer, and is shown in Figure 6. The aspheric departure was approximately 0.4 microns. The surface texture was measured and analysed using a Taylor Hobson CCI optical gauge, and the diamond-turned surface is shown in Figure 8.

After about 10mins FJP polishing on the aspheric part, the form of the part (Figure 7) was indistinguishable from the initial form of Figure 6. CCI measurements (Figure 9) showed that the Zeeko FJP process eliminated the diamond turning marks, and the Sq value was slightly improved from 4.9nm to 4.3nm. The Sa value was slightly worse, but that can be improved further by processing using the Zeeko Classic process if required.

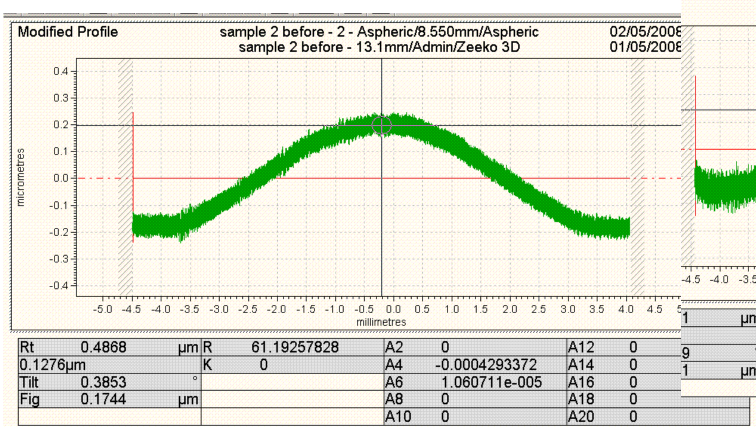

Figure 6 Aspheric form of diamond-turned electroless-nickel plated part, before fluid-jet polishing

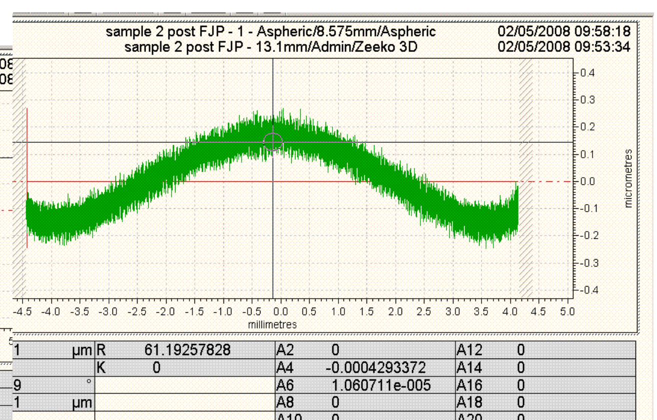

Figure 7 Aspheric form of diamond-turned electroless-nickel plated part, after fluid-jet polishing

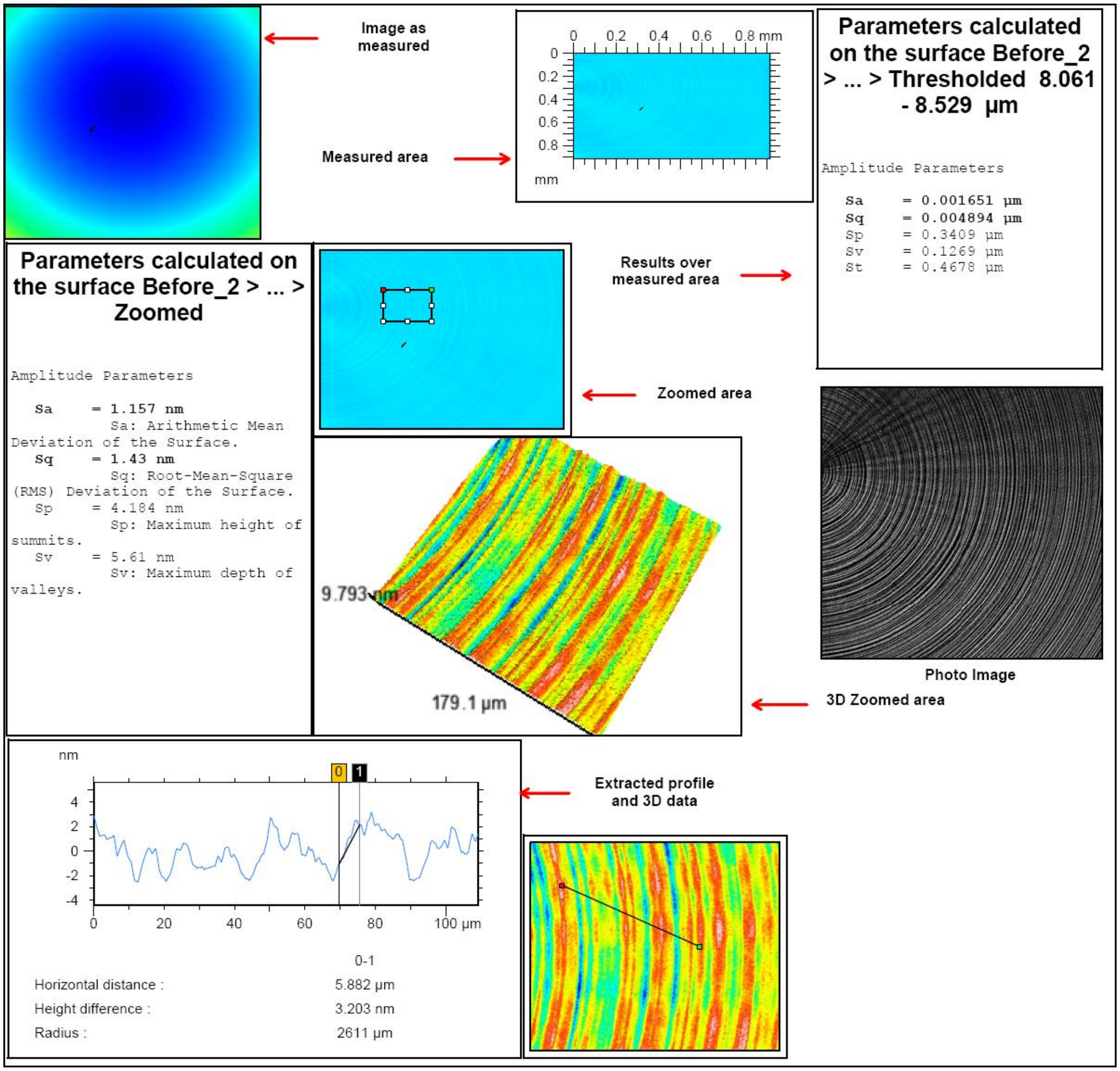

Figure 8 Surface texture of diamond-turned electroless-nickel plated part, before fluid-jet polishing

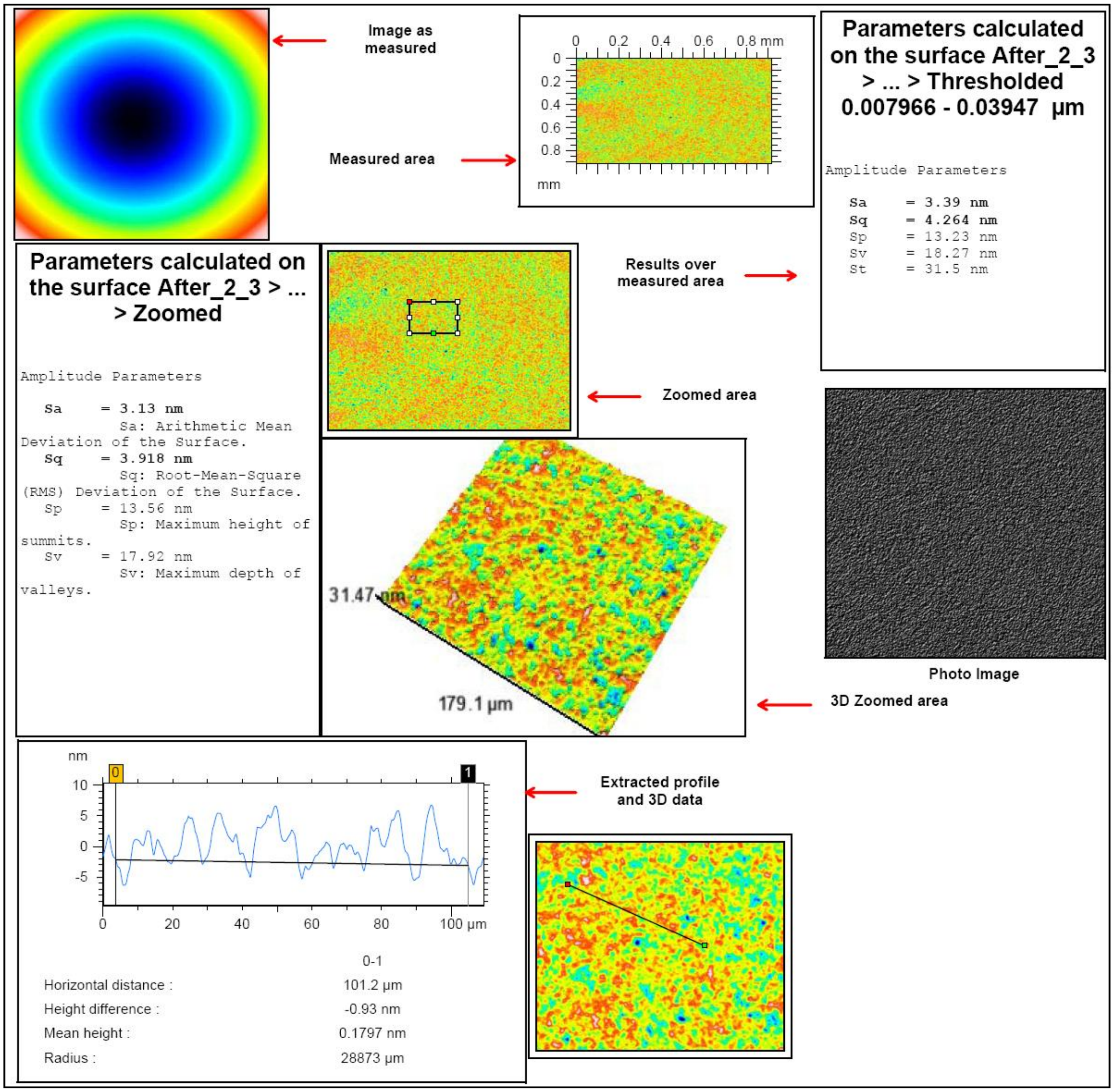

Figure 9 Surface texture of diamond-turned electroless-nickel plated part, after fluid-jet polishing

2.3 Visibility of diffraction effects

The reduction of diffraction effects is clearly shown in Figure 5. In this test, a sub-area ~25mm square of the diamond-turned part shown in Figure 1 was post-processed with cerium oxide fluid-jet polishing on a Zeeko IRP200 machine. The jet was orientated normal to the surface and the removal spot rastered across the surface. The diffraction effects from diamond-turning were effectively eliminated.

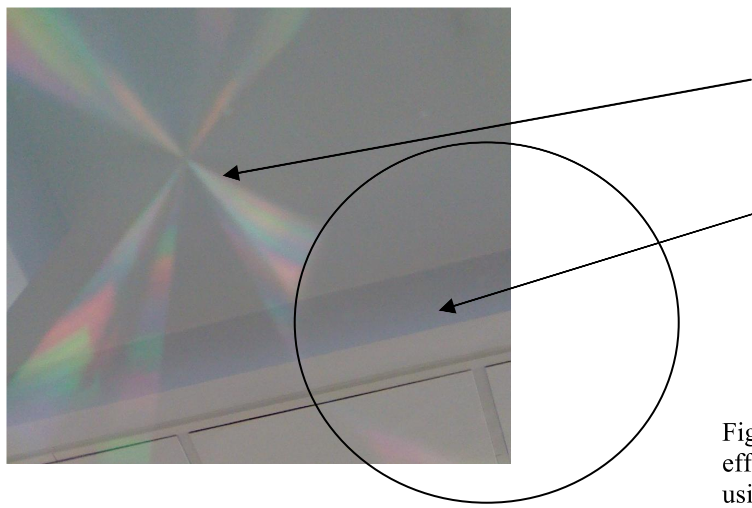

Figure 10 Removal of diffraction effects on diamond-turned surface using fluid-jet polishing

5. CONCLUSION

We have described the application of diamond-turned surfaces to aspheric mirrors, and to mandrels for replicating Walter-type X-ray mirrors. These mandrels are currently hand-polished, which can cause degradation of the aspheric form of the diamond-turned surface. In view of this, we have developed a fluid-jet technique and shown how it can randomize surfaces, removing the cyclic signature from diamond-turned electroless-nickel. This result shows considerable potential in broadening the applications of diamond-turning and avoiding manual post-polishing. Whilst effective surface-randomization is now very well established, some FJP experiments have improved the measured surface texture Sa of a diamond-turned part, whilst others have led to a modest degradation. It is not yet established whether this is a property of the polishing parameters, or the structure of the underlying electroless nickel. Further work will be required to differentiate these effects, and to optimize the FJP parameters.

6. ACKNOWLEDGEMENTS

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