Advances in Corrective Finishing of Optical Moulds for Future Aspheric Hard X-ray Telescopes

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Abstract: An innovative two-step freeform finishing method is presented, combining fluid jet and precessed bonnet polishing on a common CNC platform. Corrective and super-smoothing capabilities are demonstrated, with application to manufacturing of hard X-ray replication moulds.

OCIS codes: (120.4610) Optical fabrication; (220.5450) Polishing; (340.0340) X-ray optics.

1. Introduction

When dealing with high energy radiations, there exists a relationship between form accuracy and surface roughness of the optical surface on one hand, and the upper limit of radiation energy that it can reflect (keV) and resolution of the images it can produce (arcs) on the other hand. State-of-the-art finishing of molding dies has enabled the fabrication of X-ray imaging telescopes by replication, such as ASCA, XMM-Newton, Suzaku and ASTRO-H shown in Fig. 1. But in future years, the goal of building high resolution aspheric hard X-ray telescopes will require very stringent specification: roughness less than 0.3 nm rms and deviation from aspheric shape less than 50 nm P-V.

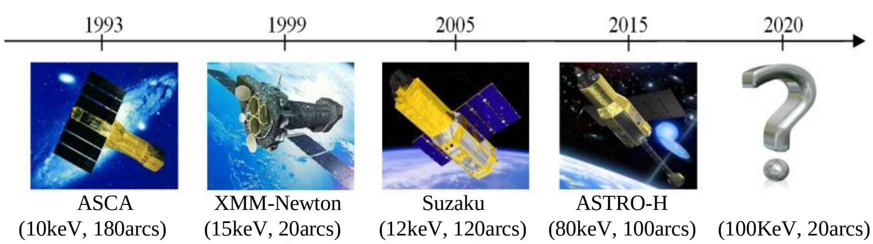

Fig. 1. Past and future specifications of replicated X-ray telescopes.

Two possible process chains have been proposed in the literature to produce future thin aspheric X-ray mirrors:

- The first process [1] relies on diamond turning of electroless nickel plated molding dies, for thin aspheric mirror replication by DC magnetron sputtering (see Fig. 2, top).
- The second process [2] relies on freeform grinding to produce aspheric fused silica mandrels, for replication of thin glass sheet by slumping process (see Fig. 2, bot).

This paper presents advances in automated corrective finishing methods, with application to both process chains.

2. Methodology

On the one hand, Fluid Jet Polishing (FJP) has been studied in recent years as a potential finishing method for optical lenses and molds with a number of materials, such a glass and nickel [3]: in this process, a mixture of water and abrasive particles is delivered by a pump to a nozzle of outlet diameter usually 0.1~2.0 mm.

On the other hand, Precessed Bonnet Polishing (PBP) is a sub-aperture

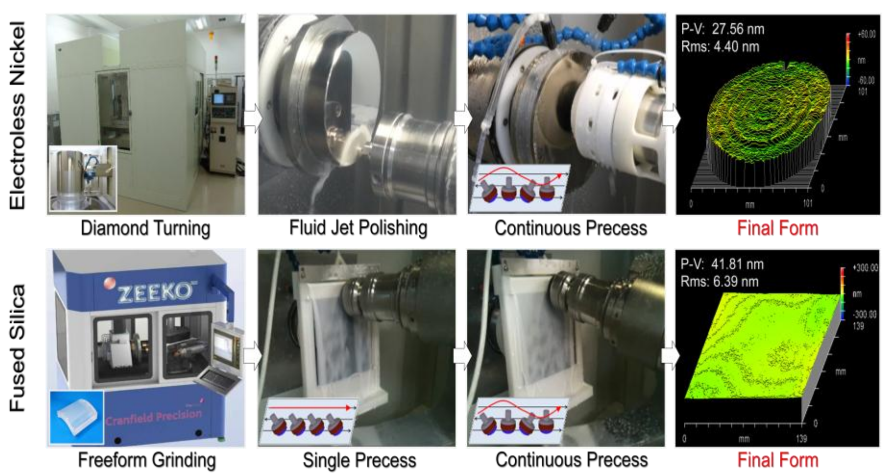

Fig. 2. Proposed process chains for producing hard X-ray replication moulds.

finishing process which has been described in the literature at various stages during its development [4]. Operation of the process in shown in Fig. 3 (center): The position and orientation (precession angle) of a spinning, inflated, membrane-tool are actively controlled as it traverses the surface of a workpiece.

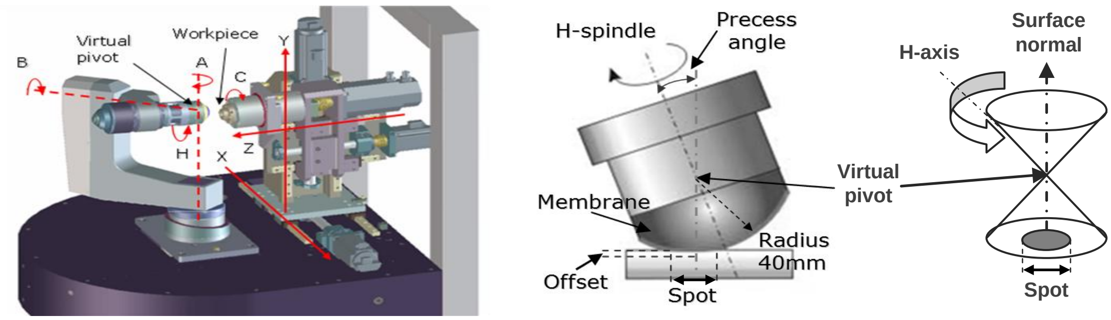

Fig. 3. 7-axis CNC machine (left), precessed bonnet polishing (center), and continuous precessing (right).

A novel concept of combining FJP and PBP processes on a common 7-axis CNC platform (see Fig. 3 left) is introduced. This combination can correctively polish ultra-precise aspheric shapes on both electroless nickel plated and fused silica mandrels, whilst efficiently removing prior machining marks (turning or grinding). Furthermore, 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 method, show in Fig. 3 (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. This method prevents directionality of the polishing marks.

3. Experimental Results

Corrective polishing by fluid jet was demonstrated on a 100 mm electroless nickel plated diameter sample, by iteratively measuring form on a Fizeau interferometer and feeding the error to a feed moderation algorithm. Initial form error on the sample was 120 nm P-V, which was improved down to 27 nm P-V (see Fig. 2, top-right).

Similarly, corrective polishing by precessed bonnet was demonstrated on a 150x150 mm fused silica sample. Initial form error on the sample was 610 nm P-V, which was improved down to 41 nm P-V (see Fig. 2, bot-right).

The 100 mm diameter sample previously polished by fluid jet was post-finished with the “continuous precess” method. Very fine slurry of 7 nm fumed silica particles mixed with pure water at a concentration of 20 g/L was fed above the bonnet with a disposable pipe connected to a peristaltic pump. To prevent drying and crystallization of the slurry on the work-piece surface, a series of pure water atomizers were arrayed around the bonnet to keep a high humidity level inside the polishing enclosure. It was thus possible to achieve a super-smooth anisotropic surface below 0.3 nm rms, as shown in Fig. 4 (right).

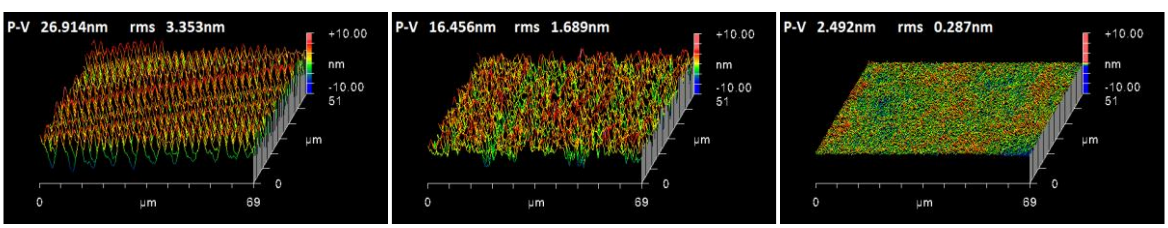

Fig. 4. Surface texture after diamond turning (left), fluid jet polishing (centre), and continuous precess polishing (right).

4. References

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