Plasma Jet Machining based process chain for the manufacturing of complex shaped synchrotron mirrors

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Abstract

An alternative process chain for the fabrication of complex shaped optical surfaces like modern synchrotron mirrors will be presented. The key part of this chain is the Atmospheric Plasma Jet Machining (APJM) step based on chemical material removal. The APJM process substitutes in a certain way the grinding and pre-polishing process of the standard chain, but has the advantage that no sub-surface damage is induced due to its chemical nature. By varying the working parameters APJM can be used for high-rate removal to achieve surfaces with large deformations from a suitable pre-shape as well as to perform surface figure error correction with nanometer accuracy and high spatial resolution.

1 Introduction

The fabrication of mirrors for soft X-ray synchrotron beam applications with aspheric geometries is still a challenging task, albeit state of the art process chains can be used as far as moderate departures from toric or cylindrical base geometries in the range of a few microns occur [1]. For those cases, full aperture tools are applied to prepare a best fitting base geometry, and Computer Controlled Polishing (CCP) or Ion Beam Figuring (IBF) can be applied for aspherization. For strong departures from the base geometry of some tens or hundreds microns a more effective aspherization technique is required, which provides significantly larger removal rates and high accuracy at the same time. For that purpose a novel process chain for the manufacturing of complex aspheric or free-form surfaces has been developed. It combines Atmospheric Plasma Jet Machining (APJM) for shape creation and shape correction, shape-preserving CCP for smoothing the surface after APJM, and, if necessary, ion beam figuring and smoothing techniques for surface finishing. APJM is a deterministic locally acting chemical dry etching technique based on atmospheric reactive plasma jets providing removal rates up to 50 mm³/min and Gaussian-shaped working functions with FWHM of typically 0.5 - 5 mm [2].

2 Machining Details

As an example the new process chain will be tested in the fabrication of a complex shaped mirror geometry suggested by Zeschke [3]. This mirror can be used for refocusing ‘astigmatic’ synchrotron light after monochromatization. It presents a new single-mirror alternative to a conventional two mirror Kirkpatrick-Baez (KB) set-up. The main benefit of a single focusing mirror would be a 4-6 times higher photon current density in the focus compared to the KB configuration. The needed surface shape is a free-form with about 80 µm deviation from a best fit torus as shown in Figure 1. The best fit concave torus with $R_{meridional} \approx 50$ m and $R_{sagittal} \approx 50$ mm over 200 mm and 20 mm, respectively, was conventionally manufactured from quartz glass. The mainly used area, where 90 % of the intensity is situated, is 170 × 4 mm².

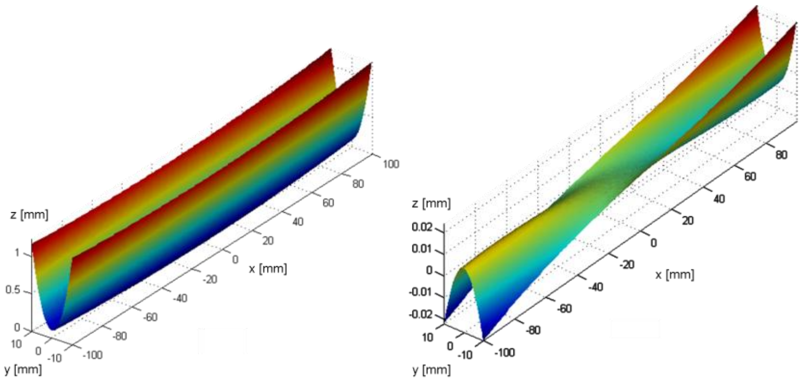

Figure 1: Goal free-form shape (left) and its deviation from a best-fit torus (right) [3].

For the primary “aspherization” of the torus a plasma jet tool with volume removal rate and FWHM around 3 mm³/min and 3 mm, respectively, was built up. The velocity dependence of both, removal rate and tool width, coming from the local temperature variation was determined by sufficient test treatments and taken into account in the removal process simulation. The machining was done using a line-by-line raster scan with a pitch of 0.5 mm, but travelling every line forth and back for thermal averaging. The velocity distribution during the primary machining step is shown in Figure 2, and the total machining time was about 1 hour.

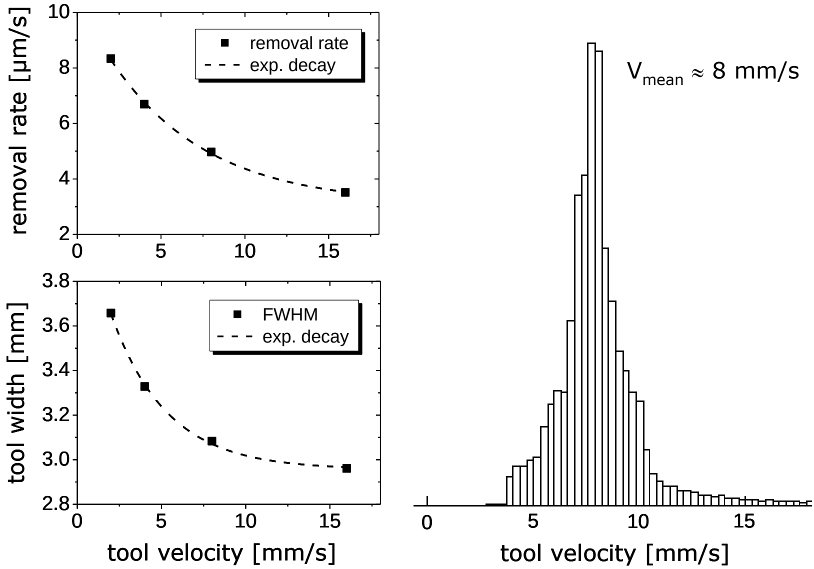

Figure 2: Velocity dependence of the removal rate and the width of the plasma jet tool (left) and the velocity distribution during primary “aspherization” (right).

3 Machining Results

After the APJM step some nearly shape maintaining post-polishing steps for surface smoothing were performed. For that purpose we used a Satisloh AII polishing robot and a Zeeko bonnet polishing tool with a radius of about 42 mm, which is only slightly smaller than the average sagittal radius of the part. The current surface shape error of the test part is about 570 nm PV over an aperture of 180 × 5 mm². The center line error is about 300 nm PV as shown in Figure 3. It should be pointed out that the surface error of the initial torus with respect to the specified shape was already in that region, which was not incorporated in the removal calculation. Additionally, due to improper cleaning of the surface prior the plasma etching process some significant disturbances occurred, which could not fully removed by polishing and hence, they are masked out. At this fabrication state the surface shape measurement was done with the help of the advanced optical profiler CT 350S from Cyber Technology. Later the BESSY NOM or the recently installed ultra-precision CMM ISARA400 from IBS Precision Engineering will be used.

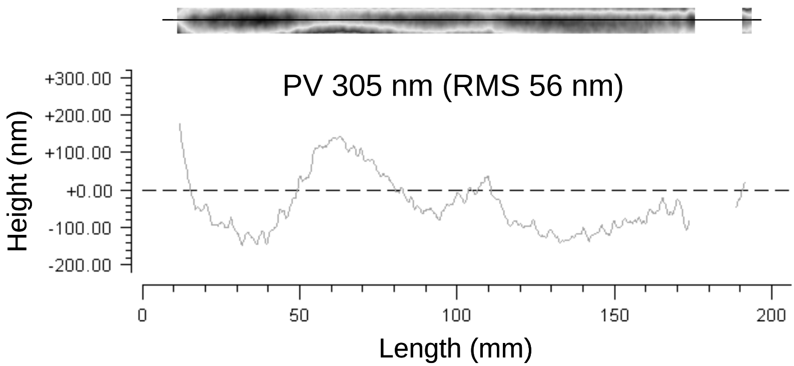

Figure 3: Current surface error along the center line of the test part after primary “aspherization” by APJM and post-polishing.

4 Outlook

Coming up next a fine correction by using a plasma jet tool with a lower removal rate of about 250 nm/s and lower tool width of about 1.2 mm FWHM will be applied, and the results will be presented. The goal for this machining step is to reduce the surface error by a factor of 10 to reach the specification of ±20 nm PV over 170 × 4 mm². Finally, the surface micro-roughness will be improved by polishing and, if necessary, by ion beam direct smoothing to <0.3 nm RMS.

References:

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[2] T. Arnold, G. Boehm, R. Fechner, J. Meister, A. Nickel, F. Frost, T. Haensel, und A. Schindler, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **616**, 147-156 (2010).

[3] T. Zeschke, BESSY (Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H.) Annual Report 2007, S. 289-291.