Edge-control on Mirror Segments

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Abstract We outline requirements for mirror segment edges for extremely large telescopes, and introduce the new CNC machine for process verification. We review a promising approach for edge-control using the *Precessions* process, and report progress.

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1. Introduction

Functionally, a segmented-mirror telescope has three fundamental differences compared with a filled-aperture telescope:- i) there are gaps between the segments, ii) there are defects ("edge roll") in the optical surfaces in the vicinity of the segment-edges, and iii) there is increased total cross-sectional area devoted to bevels. (Of course, imperfect phasing of the segments also has an effect). These combine to have several impacts on system performance, principally diffraction effects, a small loss of throughput due to the incompletely-filled pupil, increased stray-light and increased infrared emissivity.

On the last point, the astronomical detector collects infrared emission from the metal structure behind the mirror, which is at a temperature of nominally 280K. Similarly, edge-roll reflects infrared emission from the dome and telescope structure, also at a nominal 280K, towards the science detector. Bevels scatter the radiation. A terrestrial extra-solar planet might be expected to exhibit a similar surface temperature, so a small edge-roll, bevel or inter-segment gap can have a disproportionally large effect on signal-to-noise ratio and so detectability. The impact is that gaps, bevels and edge-roll must be minimized.

2. Causes of edge-roll

In classical pitch polishing, the following effects tend to roll edges:-

a) When the tool overhangs the part at the end of the machine strokes, the tool-mass clearly remains the same, but the area in contact is reduced. Hence the pressure increases and, by Preston's law, removal rate increases.
b) When the tool overhangs, it tends to pivot about the edge. In the extreme but impractical case of 50% overhang, all the mass acts on the edge.
c) When the overhanging tool moves back onto the surface, it can create a bow-wave of slurry that increases local removal.

The Zeeko Classic process deploys an inflated membrane tool ("the bonnet"), covered with an active surface such as a standard polyurethane cloth, pre-molded to the bonnet radius of curvature. This tool is first moved towards the surface, with the instant of first contact sensed by a load cell. It is then further advanced towards the surface by a calculated distance (the "Z-offset") to compress the bonnet membrane and create a defined 'spot of action'. The inflated bonnet has the advantage that it easily adapts to the local three-dimensional form of an asphere as it changes along the tool-path, avoiding the 'aspheric mismatch' experienced with hard tools. However, this very adaptability means that, when the polishing spot overlaps the edge of the part, the membrane deforms and rolls around the edge, further exacerbating the edge-roll problem.

3. Approach under development

Active edge control during polishing is under development, with the goal of applying it to segments for extremely large telescopes. This would circumvent the classical approach we have also explored, using wasters temporarily attached to the edges of the segment. Such wasters can be an effective method, but introduce the risks attendant in additional handling, in the cementing/de-cementing operation, and in warping of the optical surface. The objective is to apply the active technique to 1.4m-class segments, using the new Zeeko IRP1600 polishing machine (capacity 1.6m, shown in Figure 1) currently being commissioned at OpTIC-Glyndwr in North Wales.

Figure 1 IRP1600 machine at OpTIC-Glyndwr

In regard to the Zeeko Classic process [1,2], a consequence of the compression of the bonnet is that it can deliver a spot size which can be varied in a controlled manner along the tool-path. In practice, a set of influence functions is acquired on a witness sample, and the data are then interpolated as a function of Z-offset. In the case of edge-control, the Z-offset is reduced (tool lifted) as the leading edge of the spot reaches the edge of the part. The spot-size is thereby systematically reduced to avoid edge-overhang, or to achieve a controlled but very small overhang. These are shown in Figure 2, solid and dashed respectively.

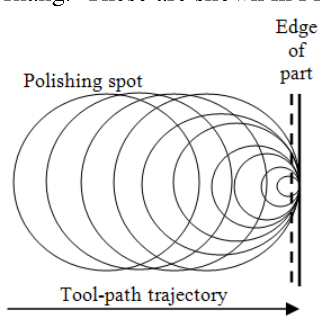

Fig. 2 Decreasing spot-size approaching edge of part

Of course, reducing the spot-size also reduces the volumetric removal rate, which can be compensated by increasing the dwell-time (in practice, varying the feed-rate). Given the family of influence function data on a witness part, the parameters can be numerically optimized. The approach can be deployed with the tool-path approaching the edge, parallel to the edge, or at an intermediate angle. It therefore covers all cases associated with a hexagonal part or other geometry.

4. Experimental results

The generalized tool-lift function capable of handling edges is implemented within the standard Zeeko software, and the principle task was to optimize parameters for the specific case. To demonstrate the technique, a witness part was bonnet-polished with a tool-path that fell short of the full size of the part, using tool-lift to leave a peripheral up-stand extending to zero removal at the edge of the part, enabling removal depth to be determined. The profile was measured (Figure 3a) using a Form Talysurf stylus profilometer, giving 18 microns removal-depth. Registration of the stylus tip with the precise turn-around into the bevel was visually observed to ensure that the profilometer plots terminated at this exact point.

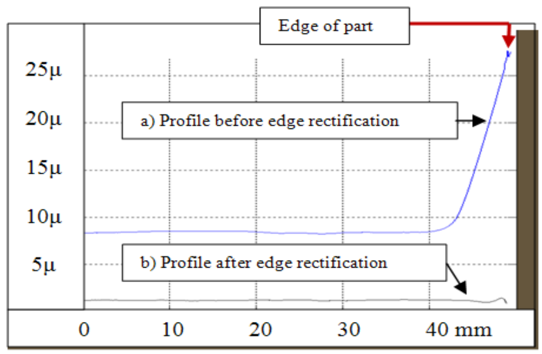

Figure 3 Profile before and after edge rectification

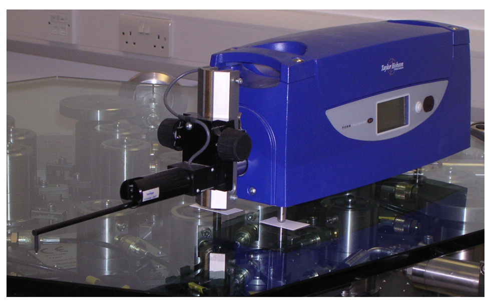

Fig. 4 Form Tallysurf Intra stylus profilometer to measure edge profiles

After applying the edge rectification method, the profile was again measured in precisely the same way – Figure 3b. It can be seen that the large up-stand has been removed leaving a small residual edge ripple. Work is currently in progress to optimize the method further to reduce this residual, before potential application on a large hexagonal part. In the case of a full-size segment, the Form Talysurf Intra is an ideal instrument to measure edge profiles, as it can be carefully located on the optical surface, given suitable protection of the contact areas. This instrument on a 1m hexagon is shown in Figure 4.

4. Conclusion

The feasibility of active edge control has been demonstrated, and may ultimately supplant wasters as a preferred method to control edge-profiles on large mirror segments and other applications. Work is in train to develop the method further to optimize edge quality and process speed.

4. References

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