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Optimisation of Grolishing Freeform Surfaces with Rigid and Semi-rigid Tools

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ABSTRACT

After the formal acceptance of our fabrication of E-ELT segments, we aim to further accelerate the mass production by introducing an intermediate grolishing procedure using industrial robots, reducing the total process time by this much faster and parallel link. In this paper, we have presented research outputs on tool design, tool path generation, study of mismatch between rigid, semi-rigid tool and aspheric surface. It is indicated that the generation of mid-spatial frequency is proportional to the grit size and misfit between work piece and tool surfaces. Using a Non-Newtonian material tool with a spindle speed of 30 rpm has successfully reduce the mid-spatial error. The optimization of process parameters involve the study the combination effects of the above factors. These optimized parameters will result in a lookup table for reference of given input surface quality. Future work may include the higher spindle speed for grolishing with non-Newtonian tool looking for potential applications regarding to form correction, higher removal rate and edge control.

Keywords: Segment mirrors, Mid-spatial error, Telescope, Grolishing, Robot, Asphere, Metrology

1. INTRODUCTION

At National facility of Ultra precision surfaces, we have successfully completed the contract of producing 5 segment mirrors for European Extremely Large Telescope (E-ELT) project. The challenges of meeting tight surface and edge tolerances at scheduled time is very high. During the process development, we found out that preparation and metrology has dominated the total process time. The next step is to development generic automation process for this project and beyond that will optimized to reduce the total process time. In optical fabrication, one major challenge is to bridge the gap of the input quality of the part to an acceptable form that can be measured and processed in-house, especially when the surface is of aspheric or free-form nature. In this paper, we are looking at free-form surfaces that has to be prepared for polishing in respect of mid-spatial features. The aim is to optimized process parameters, such as grit size, surface feedrate, head-speed etc. to provide an intermediate grolishing procedure between grinding and polishing. This will provide a guideline for process engineers of options of targeted input qualities with regard to overall process time.

Spherical surfaces are not usually the best form for lens or mirrors for most optical applications for its serious aberration problem. Optical systems can benefit significantly for using aspherical surfaces, which provide better image quality and the use of fewer elements [1, 2]. However, processing aspheric surface is regarded as one of the most difficult issues for its continuous changing surface slope along the tool path. In this paper, result for free-form surfaces grolished by both rigid and semi-rigid tool are presented. A series of experiments have been conducted using a brass rigid tool with loose Al_2O_3 abrasive to find out the relationship of grit size, misfit and mid-spatial errors; while a first trial of grolishing experiment with bounded diamond abrasive attached on a non-Newtonian semi-rigid tool has been conducted to understand mechanism between spindle speed and the generation of mid-spatial errors.

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2. GLASS BENDING EQUIPMENT

In this paper, glass is bended by the equipment shown in Figure 1 to generate free-form surface. A piece of thin glass with thickness of 3mm is attached on an aluminium plate and mounted on a stainless steel supporter. A cuboid bar attached to the plate is connected with a screw and the glass is bended by turn the screw nut underneath the equipment. The degree of curvature is decided the number of turns. ISOPON™, a flexible polyester material, is used to fill the gap between aluminium plate and the supporter. This material has a characterization to become rock-solid after air-dry for 30 min, which makes a perfect supporting layer with the same curvature of the aluminium plate to reduce uneven stress and further deformation of the glass during processing and metrology.

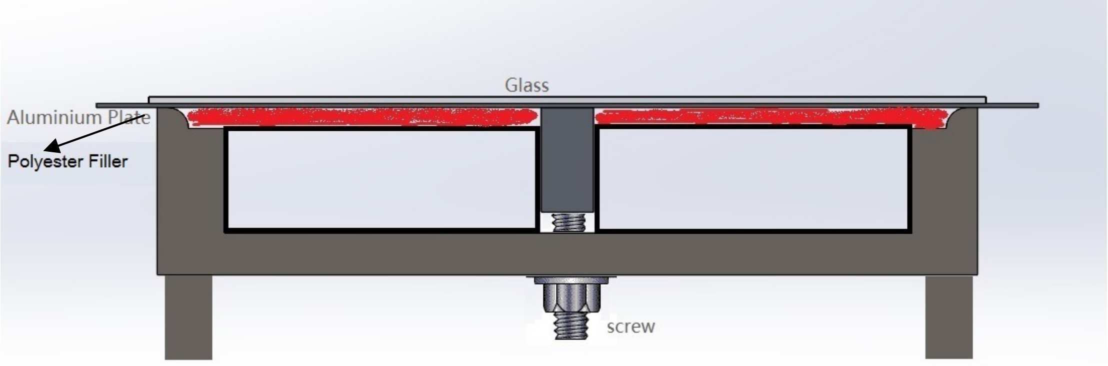

Figure 1. The schematic diagram of glass bending equipment.

3. GROLISHING ON FREEFORM SURFACE WITH RIGID AND SEMI-RIGID TOOLS

3.1 Experiment procedure

We have previous describe the grolishing procedure with robot to reduce production time and improve surface texture [3-7]. The glass bending equipment is used for both rigid and semi-rigid tools in the experiment. After being attached to the bending equipment, the 3mm thick glass was first smoothed with 9µ alumina abrasive to remove potential residue texture on the surface an then pre-polished by Zeeko 1200 mm and measured by a 4D-600 interferometer to ensure the surface do not have any mid-spatial errors left from previous procedure, which is shown from the interferogram in Figure 2. Then, the aspheric surface form was measured by the probing technique on Zeeko polishing machine and analyzed. Grolishing experiments has been conducted with different grit sizes (C9, C20 and D9) and track spacing of 10 mm, followed by polishing as a preparation for interferometer metrology. Different position of the glass surface was measure and analyzed to find out the relationship among misfit, grit size and mid-spatial errors.

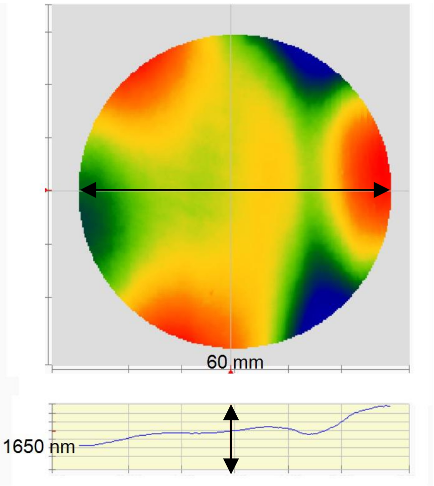

Figure 2. Interferogram of glass surface before grolishing.

Figure 3. Grolishing experiment on glass bending equipment.

3.2 Non-Newtonian material

In order to reduce the mismatch between work piece and tool surfaces, a flexible non-Newtonian material has been used according to Kim et al [8]. This material acts as a viscous liquid over a long time period but as an elastic solid over a short time period, in other words, its characterization is based on the frequency of the force applied onto it. Under low frequency condition, the material is flexible and easy to fit to the surface form, but lose the smoothing ability. On the other hand, under the high frequency condition, the tool becomes rigid and have a good smooth ability, but difficult to reduce misfit. In practical fabrication procedure, the characterization of the tool can be controlled by changing the spindle speed to meet the requirement of both flexibility and smoothing ability, but this has not been discussed in Kim's literature.

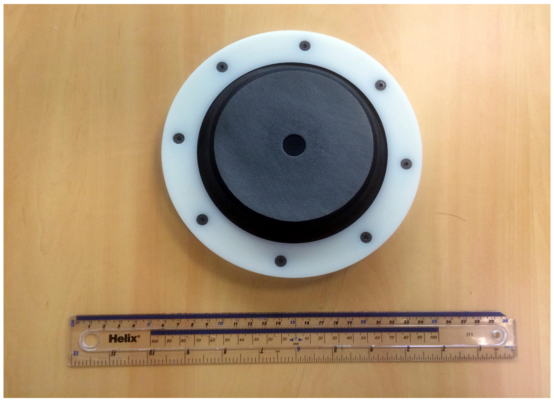

Figure 4. A non-Newtonian tool attached with diamond pad.

In this article, a first trial of grolishing experiment using a non-Newtonian tool with a spindle speed of 30 rpm and track spacing of 10 mm has been conducted on the glass bending equipment trying to reduce the effect of misfit and avoid the generation of mid-spatial frequencies. As shown in Figure 4, the non-Newtonian material is sealed in a black Bellofram attached with a 9 micron diamond pad (D9).

4. RESULT ANALYSIS

4.1 Saddle surface form

The surface form of the glass after being bended on the equipment has been measured before conducting grolishing experiments. It is expected that the bending rig will provide a cylinder form, but the surface appears to have a saddle form with PV of 200 microns, as indicated in Figure 5. This may be caused by the fact that the glass is convex with a symmetry axis vertical aligned to the bar attached under the alumina plate.

The different positions A. B and C is measured by interferometer after final polishing looking for the PV of mid-spatial errors with different grit size. With a flat rotating tool, the misfit value at different positions are expected to have the rank as follows: A>B>C, since the surface slope have the same sequence.

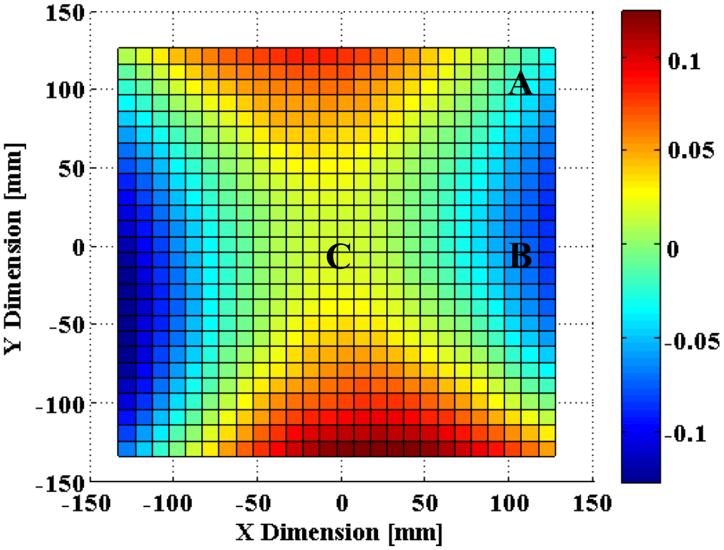

Figure 5. Surface form the glass on the bending equipment.

4.2 Experiment result with C20 and C9 abrasive

Mid-spatial errors are clearly shown in Figure 6 and the distance of adjacent peaks appears to be 10 mm, which is similar to the track spacing. The diameter for measured area is 60 mm and the scale for cross section is also given. The surface texture becomes better from the corner to the centre and this may be induced by increased misfit from A to C according to the measurement in Figure 5.

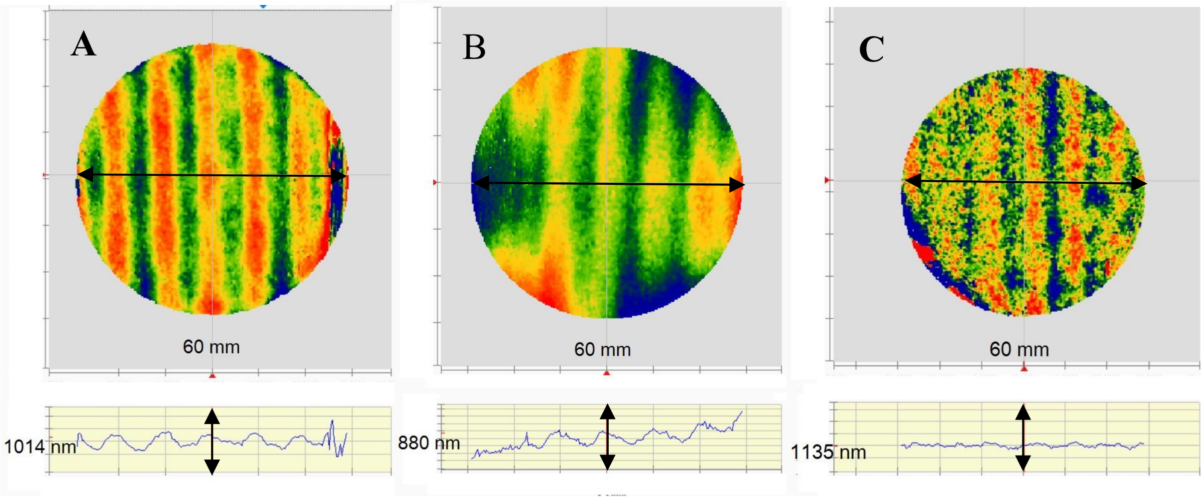

Figure 6. Interferograms for different positions on glass after grolishing by C20.

Grolishing procedure by C9 generates less obvious mid-spatial errors, while remains the same trend of reduced PV from corner to centre. It seems that smaller grit size could provide better finishing of the surface, but it can also be explained by the reduced removal depth by using smaller grit. Future research shall be conduct to ensure the same removal depth for different grit size and then compare the results.

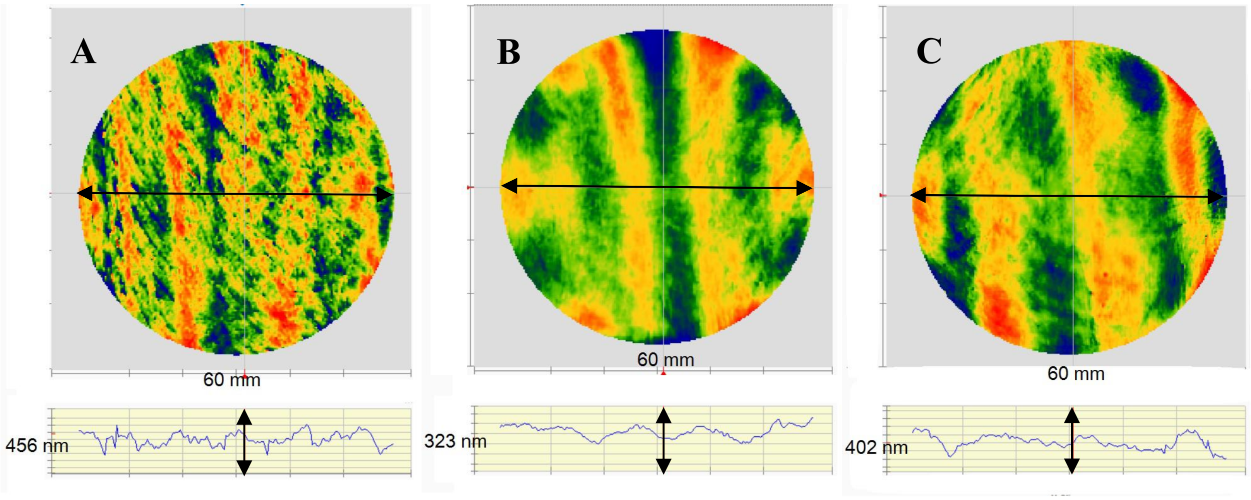

Figure 7. Interferograms for different positions on glass after grolishing by C9.

4.3 Experiment result with D9 abrasive

The mid-spatial errors has been significantly been reduced by using a non-Newtonian tool with a spindle speed of 30 rpm. The results shows that under this spindle speed the tool is flexible enough to adapt to the saddle working surface, thus reducing the misfit and improving the finishing quality. More experiments shall be conducted with higher spindle speed to verify this guess. This theory may have many applications regarding to the optimization of surface texture, removal rata and edge control for precision optical processing.

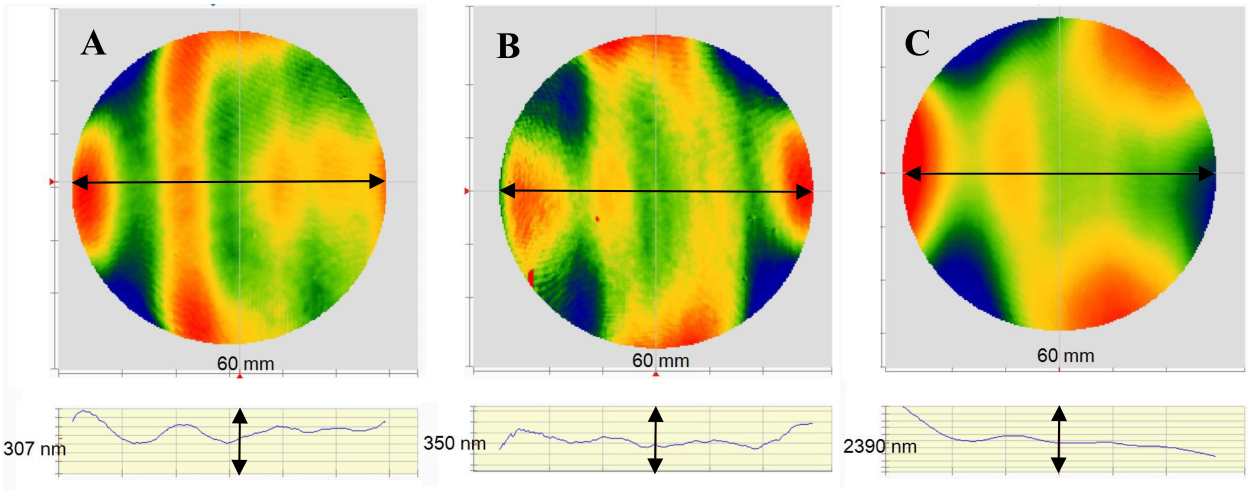

Figure 8. Interferograms for different positions on glass after grolishing by D9.

Table 1. Adjacent PV of mid-spatial errors for different positions after grolished by different abrasives.

ABRASIVE	A	B	C
C20	221 nm	177 nm	102 nm
C9	136 nm	85 nm	67 nm
D9	62 nm	N/A	N/A

5. CONCLUSIONS AND FUTURE WORK

It has been indicated mid-spatial errors are generated during the processing on free-form surface due to the serious misfit. The PV of mid-spatial frequencies is proportional to the increase of misfit between work piece and tool surfaces. Grolishing by C9 provides a better surface finishing compared with C20, but this could be caused by different removal rate. Future research shall be conducted to quantized investigate the mechanism for the generation of mid-spatial frequency.

The use of non-Newtonian tool shows tremendous advantage on reduce misfit with low spindle speed. Future work shall be conducted with higher spindle speed looking for optimized parameter for delivering both good surface texture, removal rate and smooth ability. Non-Newtonian material tool with different spindle speed may be applied to optimize various optical fabrication issues, including improving removal rate, surface finishing, reduction of mid-spatial errors and edge control.

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