New opportunities of freeform gratings using diamond machining

Dispersing elements for Astronomy: new trends and possibilities – 11/10/17

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Plan of the talk

- Introduction on diamond machining
- Advantages and limitations of this technique
- Integrated gratings imaging spectrograph
- Overview of elliptical gratings
- Characterisation of diamond machined gratings through a project funded by CEOI
Basic Specification

- 5-Axis Configuration (X, Y, Z, B, C)
  - Workpiece Capacity : Φ 600mm
  - Travel X: 350mm, Y: 150mm, Z: 300mm

- Granite Base with passive air isolation

- Programming Resolution
  1nm - Linear Axes
  0.036 arcsecs - C-axis
  0.02 arcsecs – B-Axis

- Feedback Resolution 0.034nm on linear axes
Advantages and limitations of diamond machining

- Machining in its functional orientation and position
- Blanks can be pre-machined in all sort of shape
- Full control of the groove profile:
  - Echelle grating
  - Multi blaze structure
  - Variably spaced grooves
- Improved thermal performance of metal optics at cryogenic temperatures: new type of ultrafine aluminium alloys
- Large sag, steep slope
- Quick set up and program, cost effective
- Tool wear, inducing variations in the groove’s shape
- Thermal variation during machining => long machining time
- Ultra smooth surface where post polishing is not required.
- In the best cutting conditions, roughness can be as low as 1nm RA.
Grating specification

- Max size: ~250mm x 140mm (along the groove direction)
- Frequency: typical 100 lines/mm up to 1000 lines/mm (depending on grating size)
- Material: metallic substrate
  - standard aluminium 6061 T6
  - Melted spun aluminium alloy from RSP (RSA 6061 T6, RSA 443)
  - Brass, coper
  - Nickel plated metal

4 axis of the machine are used at the same time:
- X, Y, Z => for ruling the grooves on the freeform surface
- B axis => rotation of the tool for keeping the blaze angle constant when the gradient changes
Multi blaze

- Coarse grating: 2mm period
- Blaze angle: 3 and 6 degrees
Dual Blaze

- Frequency: 10 microns
- Input angle: 3°
- Diffraction order: +1

Linear variation frequency

- Coarse grating: 0.4mm => 3.6mm
- Blaze angle: 5°
Design of elliptical gratings

- Sphere constant pitch
- Asphere constant pitch
- Asphere variable pitch

R 200-300

R 1500

0.15 micron variation

Quadratic variation frequency

- Coarse grating: 2mm => 3.25mm
- Blaze angle: 5°
Freeform gratings – improved compactness

- Grating fabricated onto a curved (freeform) surface
- The dispersion element can be integrated with the IFS pupil mirrors
- Replace the pupil mirror, grating and camera optics with a single optical element.
- This will significantly reduce the complexity and increase modularity and compactness
First integrated grating imaging spectrograph (IGIS)

- Collaboration between Durham University and University of Florida
- Airborne IFU working at low spectral and spatial resolutions in the visible range
- Design all aluminium
- Diamond machined in its functional position
- 12 slices covering a FOV of 1.1 x 0.3°

Elliptical surface

Tilted Ellipse

- F/6
- Wavelength : 1.2 μm
- Square FOV : 4mm
- Off axis : 20mm
- Magnification : x0.3
Elliptical grating diff order 1

Elliptical grating

- F/6
- Wavelength : 1.05-1.35 µm
- Spatial FOV : 4mm
- Off axis : 20mm
- Magnification : x0.3
- Period : 150 l/mm
- Diffraction order : 1
- R : 2250
Elliptical grating

- F/6
- Wavelength band: 1.1-1.3 μm
- Spatial FOV: 4mm
- Off axis: 20mm
- Magnification: x0.3
- Period: 150 l/mm
- Diffraction order: 1
- R: 6750

=> Higher diffraction order possible at the cost of reduced wavelength bandwidth.
CEOI Project description

• Investigate technical feasibility, performance and limitations of metallic freeform blazed gratings produced by diamond machining.
  ▪ Materials comparison:
    ➢ RSA 6061 versus RSA 443 with Nickel plating
    ➢ Same grating design (pitch/blazed angle freeform shape)
• Develop the software tool for the machining of:
  ▪ Multiblaze structure
  ▪ Variable frequency grating
• Determine the optimal cutting parameters
  ▪ Feedrate & tool wear
• Grating Characterisation in term of:
  ▪ Spatial and spectral resolution
  ▪ Surface form error
  ▪ Roughness
  ▪ Efficiency
Hyperspectral imager for Earth Observation

Overcome the limitation by incorporating gratings within IFU and by customizing them for spectral resolution and bandwidth.

Customization can be:
- Different groove spacing
- Different order
- Different blaze angle
CEOI Project description

- Design of a 50mm grating, optimised for some of the strong lines of a Neon lamp.

- Theoretical R : 4500

- Elliptical surface composed of a nominal spherical surface (1mm) + astigmatic surface (1.5micron)

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>FOV object (along the spatial direction)</td>
<td>+/-2mm</td>
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<td>FOV image (along the spectral direction)</td>
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<td>Input F number</td>
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<td>Distance object</td>
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<td>Grating diameter</td>
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<td>Optimisation Wavelength</td>
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<td>number of line / mm</td>
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<td>Diffraction order</td>
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<td>incidence angle at 588nm - centre of the grating</td>
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<td>shape</td>
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</table>

![Efficiency graph](image)

![Freeform SAG (mm) and Freeform SAG at best fit sphere (micron)](image)
• Diamond machined freeform gratings can complement alternative technologies such as ion beam etching with holographic masks and offer a full control on the blaze structure. They can easily be implemented with:
  ✓ multi-blaze (broadening of the wavelength bandwidth)
  ✓ variable frequency (further improvement in the spectral resolution) on high sag, large slope surfaces.

• A new design of Integral field spectrometer: integrate freeform gratings onto the pupil mirrors, significantly reducing the complexity, at the cost of a FOV and spectral range set by the design parameters.

• Work in progress at Durham University for the development of novel machining strategies to produce and improves metallic diamond machined gratings.