Fabrication of Freeformed Blazed Gratings by Ultraprescision Machining

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Abstract

There are a few methods to produce high quality plane symmetric gratings. But until now it was only possible to produce blazed gratings with so called grating machines. This is a mechanical process and the grooves are divided with a special formed diamond tools in thin metal layers. Because the material is reallocated during this process it is difficult to produce coarse gratings without deformation of the structure. Hereinafter, a method is presented to produce blazed gratings with a planning process. The structures are not deformed and there are no limitations to substrate forms.

1 Produced structures

With this process it is possible to produce differed types of gratings. The blaze angle is not restricted and even echelle gratings with angles up to 80° and densities down to 15 grooves per millimetre were produced. On the other hand also typical echelette gratings with line densities up to 300 grooves per millimetre and blaze angles down to 3° were produced. The substrate form is not limited and gratings were planned in spherical (concave and convex) substrates. Different types of substrate forms are also possible. The radius of curvature and the maximum differences in height are not restricted. Gratings with a radius of curvature between 8 and 300 mm were already produced. The blaze angle can be changed for every groove. So it is possible that the grating normal is always perpendicular to the substrate surface. It has been also shown that it is possible to fabricate two or more different areas of blaze angles in one grating without a border between the areas (fig. 1).

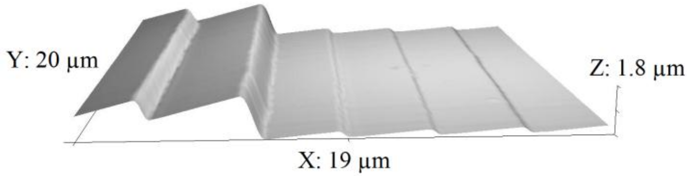


Figure 1:AFM measurement, grating with two different blaze angles (3° and 15°)

2 Used machine

A modified and improved ultra precision milling machine LT-Ultra MMC-1100 (fig. 3) [1] was used to fabricate all of the gratings. The tilt and rotation module (fig. 2) [1] adds two additional rotation axes which allow changing the angle of the diamond planning tool directly during fabrication.


Figure 2: Tilt and rotation Module

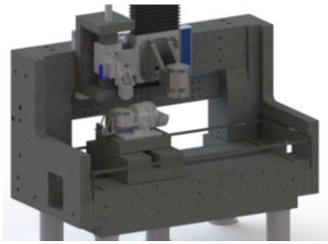


Figure 3: LT-Ultra MMC-1100

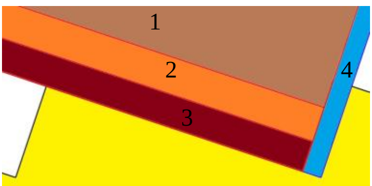
The base structure of granite reduces vibration and temperature effects. Additionally an active air damping system isolates the machine from the ground to achieve very low roughness values on the gratings. A high stability of the groove density is achieved with the linear motors controlled by corrected glass scales. The used correction algorithm will be described in further publications. In combination with the hydrostatic bearings there is no stick slip and a start-stop-motion of the slow axis is used for fabrication.

2.1 Tool alignment

Synthetic monocrystalline planning diamonds were used for fabrication. With an adjustment device it is possible to bring one of the tool corners direct in the rotation axis of the tilt and rotation module. The adjustment is done with very fine adjustment screws on solid state joints and monitored with a high resolution video capturing. An inbuilt vacuum chuck is used to fixate the tool after adjustment. This procedure is essential because if the corner is not exactly in the rotation centre the lower blaze edge will shift over the grating length.

3 Fabrication process

The material is removed via planning/cutting from the substrate. The position and angle of the tool is NC-controlled. To achieve high quality blaze surfaces a multi-cut-process was used. Dependent on structure geometries several pre-cut cycles are needed to remove material with no measurable wear to the diamond (fig. 5). The last finishing step (fig. 6) and the correct choice of the offsets select the blaze facet (echelette or echelle). If this step is missing it is impossible to produce echelle gratings because the chip is ripping on the steep blaze and cut on the antiblaze. This step is not required for echelette gratings but it improves the roughness. A schematic visualisation of the cutting steps is shown in fig. 4 for an echelle grating with a total of 4 cuts. The gratings were machined into electroplated gold with the use of lubricant. The surface structure of the gold is of no importance because it will be removed and only the homogeneity of the gold must meet higher claims. The use of lubricant reduced the measured planning forces down to 60% and influences the chip behaviour positive.



Figire 4: Multi-cut process (1-4: sequence of cuts)

Figure 5: Pre-cut

Figure 6: Finishing

4 Parameters, “ghosts” and quality

The fabrication paramters directly influence the rougness and thus the quality of the blaze. The chip surface and the feed influence the force on the diamond and the wear. The smallest burst on the cutting edge will increase the stray light. The cutting forces were measured to identify parameter sets with low wear and good surface quality but will be presented in further publications in more detail. A small infeed between 2 µm for echelette and 4 µm for echelle gratings with a feed greater 1000 mm/min gives the best results and an area roughness below 2 nm was realized. The stray light was measured in the littrow-blaze condition with a HeNe-Laser. The signal period of the glass scale is too small to produce rowland ghosts [2] but lyman ghosts [3] still occur if no correction is used. This is an alternative to the typical used laser interferometers first presented by Harrision [4] to control the slow axis. In figure 7 are examples of a stray light measurement with a satellite caused by non periodical errors due to material inhomogeneities and a stray light measurement of a high quality grating with an almost ideal order. The stray light of the high quality grating in this example is below 0.0001 at the used wavelength.

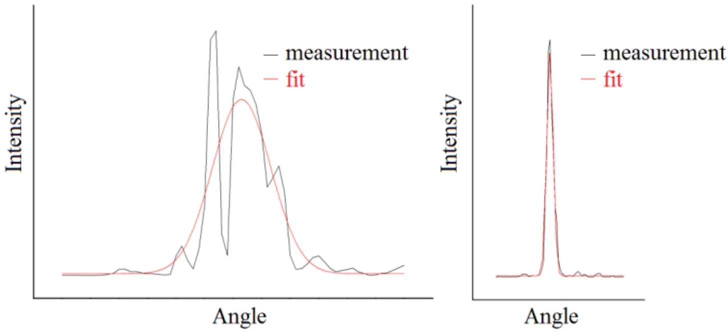


Figure 7: Stray light measurements, left) with satellite, right) ideal order

5 Summary

It has been shown that it is possible to produce high quality plane and spherical gratings. The multi-cut-process reduces the roughness of the blaze down too 2 nm and even ghost and other errors don't appear. Additionally the blaze angel can be changed for every groove and the structures are not deformed. Thus planning is an adequate process for grating fabrication.

References:

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