

Recent Technology Advances in Diamond Machining for Space Borne Optical Systems

Corning NetOptix
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In the past, single point diamond machining was a manufacturing technology restricted to infrared applications, due to the more forgiving nature of the optical requirements with regard to figure/form and finish/micro-roughness. Machining platforms were typically configured as lathes or flycutters, enabling them to produce flats and rotationally symmetric surfaces including off-axis aspheres that were within their “swing” capacity or travel.

These precision CNC machines incorporated air bearing spindles and slides, and used lasers for position feedback. Precision single crystal diamonds were used as cutting tools to machine optical surfaces into a number of non-ferrous metals as well as IR crystalline materials such as germanium, zinc selenide, and silicon.

Recent technological improvements in machine tool; position, resolution, motion control, diamond tool quality, and fixturing techniques have allowed for production of both visible and UV quality optics. Furthermore, additional axes of machine tool control have further extended capabilities to include free-form components such as; optical segments of very large “parents”, bi-aspheres, aspheric cylinders, and phase-correction plates. Innovative, new configurations now allow production of spherical and aspheric lens arrays, image slicers, reflective Vis/IR gratings, corner cube arrays, as well as micro-prismatic structures (typically seen throughout display technologies). Advances in post-processing of diamond machined components reduce the diffractive effects (diamond grooves) that are typical of traditional turning techniques.



These next generation diamond machining techniques have been applied to a number of military and commercial applications including infrared imaging systems, hyper spectral imaging systems, image slicers, and molds for the ophthalmic and display industries. This paper will serve as an introduction to some of the nuances of single-point diamond machining technology and associated technologies that when used together will challenge the traditional boundaries and understanding of optical fabrication, using single-point diamond turning.

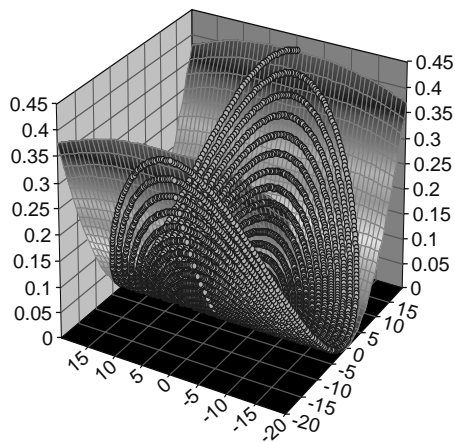
An example of a common diamond machined optical component would be a reflective off-axis parabola, machined into an aluminum substrate. This monolithic component enables the mechanical designer to incorporate mounting features that will ensure precision alignment into a diamond machined housing of the same material, providing for system level thermal stability. “Snap-Together” construction has been coined to describe such techniques. One can imagine the further downstream advantages with respect to assembly and test, as well as cost, which “snap-together” construction offers.



This is an example of one of the many, already “well understood” advantage of diamond machining. Using this as our foundation, one could now imagine the advantages associated with the incorporation of aspheric/free-form prescriptions, image slicers, reflective gratings, and lens arrays, as components to an optical train, in a “snap-together” type system.

Free-forms have been produced for many years by a process referred to as “raster fly-cutting.” Non-rotationally symmetric parts have historically been diamond machined with a raster milling process on three-axis CNC machines. This process is quite inefficient resulting in compromises between figure and finish. For example, the finish can be improved by programming finer “step-overs,” but at the expense of run time and hence figure. The resultant finish requires post polishing for most applications.

XZC toolpath for machining a cylinder

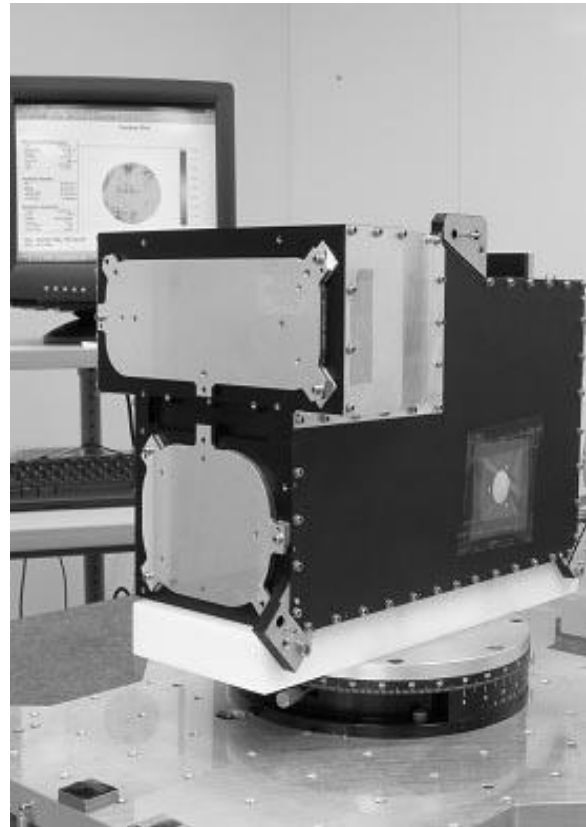


With recent improvements in computer control and position feedback resolution, a generation of diamond turning machines tools have become commercially available and capable of machining non-rotationally symmetric optical components. One version of these new machines is referred to as slow tool servo lathes. These lathes incorporate high resolution encoders to position the spindle dynamically relative to x and z slide positions.

An off-axis segment of an asphere can be considered as a free-form. A new equation can be derived for the sphere with the origin at the center of the aperture and the optical surface tilted to minimize departure from rotational symmetry about the new origin. Special tooling can be designed to assure fixturing to these parameters. The results have met the needs for a number of IR systems.



Interferometric test of complex aspheres and other non-rotationally symmetric components has followed the technological advances which made the producibility of these parts a reality. There are a variety of ways to ensure the optical performance of the component and/or system under test, although some may not be intuitively obvious. CGH's (Computer Generated Holograms) have been the most popular choice for interferometric test of aspheric surfaces. These bring with them, their own, unique set of challenges which include tip/tilt errors and proper interpretation of coma/astigmatism. Less expensive alternatives also come with their own unique challenges or limitations. If space permits, programming of a sphere, outboard/inboard of the clear aperture, can allow for some level of test. Certification of the aspheric contour is then left to program accuracy. Concerns regarding tool wear and fixturing could also be inferred by the quality of the "fiducial" in/outboard.



These methods, in conjunction with "snap-together" system level test, allow for alternatives at final assembly. It is possible utilizing the techniques described above to assemble the system and then compensate by finish machining a selected component within the final system. This would be a similar approach to production of a phase-correction plate. Although this method of assembly may not be ideal, it is now possible utilizing many of the techniques and technologies represented throughout this paper.

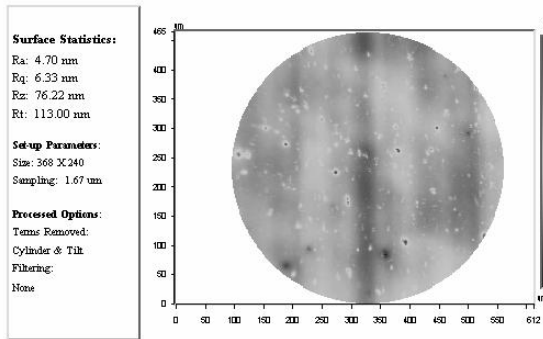
Traditional diamond machining technology for UV and VIS applications has been met with some skepticism over the years, due to diamond turning grooves that become part of the optical surface during fabrication. The use of these components in IR systems has been widely accepted, yet visible and UV applications have typically "closed the door" on this technology. Today, there are a variety of technologies that make UV and Vis optical component and system production possible using single point processes. Corning has developed the LEC machining/polish process reduction of the machining grooves in 6061 aluminum substrate. Although the details are considered propriety and competition sensitive, it can be said that the LEC process offers both the accuracy of diamond machining (programming to within millionths of an inch) and the elimination of

diamond machining grooves (superior surface finish on both flats and contoured surfaces.)

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Surface Data

Mag: 10.1 X



Title: 6061 Aluminum
 Note: DT Gen 1 with LEC

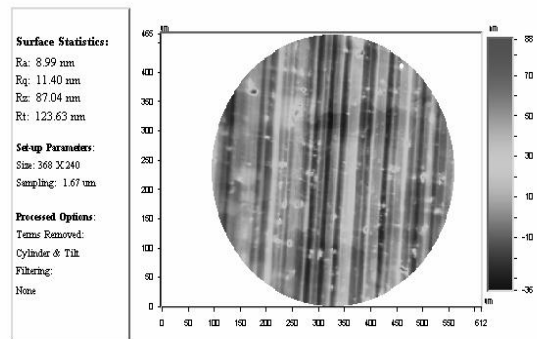
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Surface Data

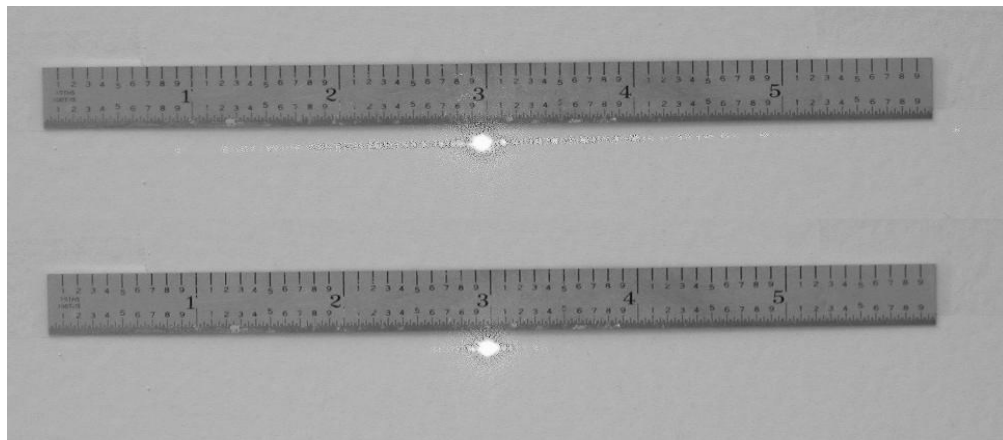
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Time: 12:15:39



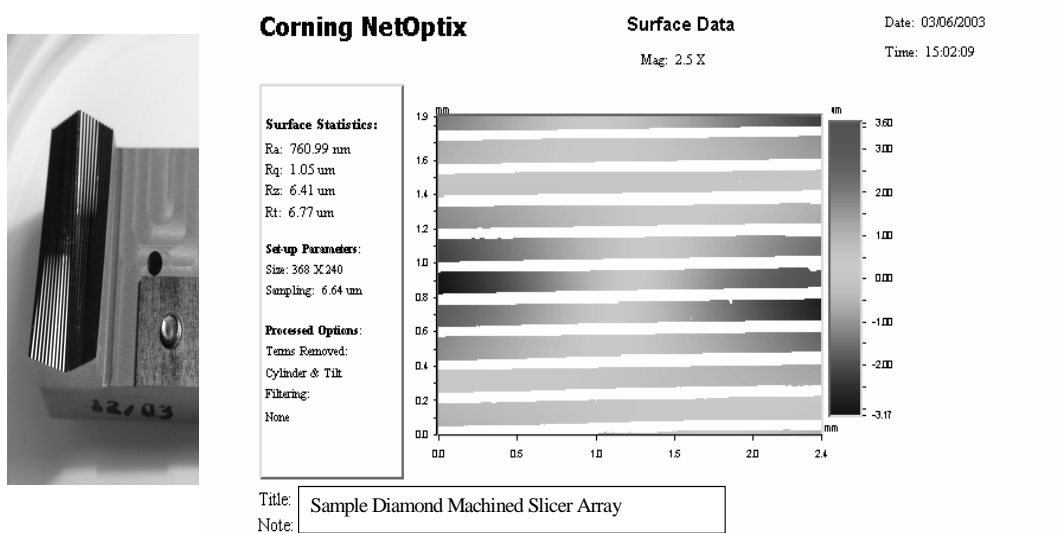
Title: 6061 Aluminum
 Note: as DT on Gen 1 machine

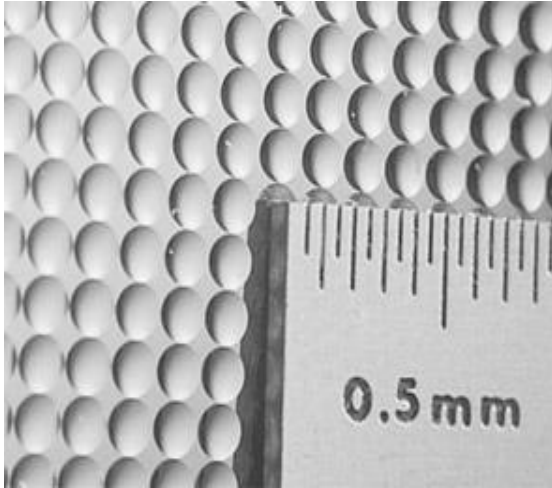


Derivatives of Corning's LEC process have allowed for variations of the technology which employ a deliberate distortion of the optical figure. These approaches can be compared to more traditional methods of polishing, but again utilizing the accuracy of the newest generation diamond turning platforms to bring the substrate to "near net shape". This will again allow for a cost effective approach to manufacturing, but will open the door to UV and Visible applications. LEC figuring has produced 1/10th wave optics P-V and diffraction-free surface finishes at <20A RMS.

Corning has ongoing studies utilizing an LLC material. Although there is not enough flight or space qualified data to market this material, this post-processed aluminum alloy should be mentioned. Corning's LLC material has demonstrated significantly reduced measurements of RMS surface roughness over commercially available aluminum alloys. Measurements approaching the single-digit angstrom level RMS surface roughness have been consistently achieved. The application potential for this material is truly intriguing.

Recent challenges presented to the diamond machining community involve reflective "image slicers" used to dissect an image for spectral analysis. This application presents significant challenges in the manufacturing process. The use of specialized diamond machining centers and custom tooling, have enabled the precision manufacture of thermally stable, dimensionally accurate, components with precision alignment features. These have been manufactured for IR and visible applications. Significant potential lies, not only in the use of this technology for imagine slicing, but also as a means to concentrate laser energy, in high energy laser applications. Corning has continued involvement in both areas.





Single point diamond machining has also been utilized in the production of lens arrays for beam alignment. Lens arrays have been produced in many configurations and for a multitude of applications, both commercial and government. Although these typically have been spherical, aspheric, torric, and free-form profiles have also been manufactured. Again, used in conjunction with other “precision aligned”, “snap-together” optics, the advantages become readily apparent.

Reflective gratings for applications such as infrared and visible hyper spectral imaging system have been successfully machined into metal substrates. Propriety processes assure precision alignment, thermal stability, and improved performance (by allowing variable pitch and blaze angle). Due to the nature of diamond machining and the fabrication techniques employed, it is possible to produce these gratings on an almost unlimited number of base surfaces or contours. Corning has successfully produced spherical, torric, aspheric, gratings, as well as gratings on flats.



Grating testability has also presented significant challenges, with regard to grating efficiency and BRDF type measurements. System level test and some proprietary approaches have led to innovative new methods to test at the component and system level.

Prismatic structures such as linear grooves, pyramids, corner cube arrays and moth eye structures have been machine for a variety of applications.



In conclusion, it should be stated that in addition to the techniques and technologies described above, there are a variety of custom diamond tools, cutting fluids, cutting geometries, fixturing approaches, and programming techniques that have not been described in this paper. Single-point diamond machining has continued to develop as a manufacturing technology. The use of diamond turned optics for a variety of UV, Vis, and IR applications are now possible.