Fabrication of Freeform Optics

Brian Creber, President
B-Con Engineering inc
Unit 20, 20 Gurdwara Road
Ottawa, Ontario, Canada K2E 8B3
www.bconeng.com

Abstract:

B-Con Engineering has been working in the area of design and fabrication of freeform optics for the past 2 _ years with the installation of a Moore Nanotech 500FG Ultra-Precision Freeform Generator. In this discussion, we will address areas of process including interfacing the standard design software output with machine code for operating the Freeform generator, materials compatibility, metrology, applications, and challenges for the future.

Freeform Surface Applications:

There have been two areas of design of freeform optics that B-Con Engineering has concentrated its effort. One area is the use of freeforms to reduce the number of elements in an optical system, while being constrained to correct some form of image distortion. We have worked with a European company to create a heads up display system that provides an excellent quality image, while correcting for the image distortion generated by a non-flat windscreen. This product is released to the market in the M7 series produced by BMW. In this application the optics are first surface reflectors, hence, most of the work has involved precision grinding of tool steel with the optics being molded in Europe.

A second application area which has progressed through the fabrication of freeform prototypes to freeform optical molding is automotive forward lighting applications using high power white LEDs. In this application freeform optics are used to direct and concentrate the LED to meet Federal lighting standards. These optics are transmission elements, with the initial elements freeform fabricated on the Nanotech 500FG, and later, freeform molding tools were ground on the machine.

Some of the details of these and other applications will be discussed later.

Design Software Interface:

The freeform generator operates using standard machine code (G-code) and though some of the CAM (computer aided manufacturing) softwares such as Mastercam would seem to be applicable to converting to machine operating code for freeform surfaces, unfortunately, the methods of treating surfaces in these softwares lead to positional errors in creating tool offsets paths.

B-Con Engineering opted for a method of taking mathematical surface data from the optical design software (Zemax, Oslo, CodeV or others) and writing tool off-set routines using MathCAD to generate the off-set tool code which is the basis of a G-code routine for the freeform generator. This design method has no constraints as to the form or number of terms in the 3d equation for the optical surface, unlike other diamond turning softwares which allow only a limited number of terms in the aspheric equation. The method also allows us to create subroutines which translate, and rotate the co-ordinate systems of the optical equation so as to conform with the machine co-ordinate system. This translation and rotation requirement is also unlike on axis diamond turning, which is constrained around the spindle axis of the machine.

The method, however, requires that we characterize the cutting or grinding tool before we complete the final tool path, which requires close co-ordination between the freeform generator operator and the programming Engineer as a typical surface tool path generation takes a few hours during which time the freeform generator can not start the grinding or cutting job.

The software Engineer's job does not end with the tool path generation as there is no freeform metrology software for the Moore 500FG. The freeform generator has a contact metrology system on board using the WECS system developed by Moore. The software has been developed around rotationally symmetric metrology, with features such as compensation for cutting errors for these rotationally symmetric surfaces. The case of freeform surfaces does not have error comp, however, the metrology has been left open ended so that our software Engineer can write a theoretical surface profile program in 3D, use the on board metrology, and measure the deviation from the theoretical surface. Again, the metrology routine can only be run after the probe is mounted and calibrated (after the part has been cut or ground).

Materials and Tools:

Freeform shapes are usually generated on the Moore 500FG using a method of raster grinding or raster flycutting using a single point diamond tool. The system itself is very mechanically stable, and has a wet cooling system which maintains the temperature of the spindle, work area, work, and tool. The temperature control is very important as the typical runtimes are in excess of 24 hours.

We have been successful grinding and/or diamond turning materials such as plastic resins, aluminum, AlBeMet (Aluminum/Beryllium alloy), copper, hardened tool steel, SiC, optical glass, and fused silica.

The very low grinding forces used by the system has made the process particularly successful on lightened structures of optical glass, and light weighted aluminum.

Challenges for the Future:

Freeform optics have interesting applications in the area of LED lighting, compact projection Television, Heads up Displays, conformal optics (aerodynamic and hydrodynamic) for imaging. The benefits of using this type of optical surface to reduce the number of components and the complexity of the optical system outweigh the challenges of mass producing these surfaces.

Our application in the automotive heads up display showed the benefit of using molded first surface reflectors of polycarbonate, and the process for achieving reproducible surfaces, however, did highlight the challenges and need for on line metrology in a molding plant for this type of surface.

Our forward lighting application using white LEDs required complex freeform surfaces to control and direct the light source, pointed to the challenge of using currently available mold tool materials (hardened tool steel) and the difficulty in grinding high quality optical surfaces with very small features in these materials. Surface metrology for the molded parts was again a challenge.

Other applications in conformal optics, and tools for molding finished freeform surfaces in glass and fused silica, have, similar challenges in terms of materials and metrology.

Key words: Freeform, Conformal