Chapter 1
Trends in Manufacturing for Aspheric and Freeform Optics

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Abstract Complex surfaces such as aspheric and freeform surfaces have advantages over conventional spherical surfaces in imaging and non-imaging applications. The use of aspheric and freeform surfaces in the optical system provides more degrees of freedom to the optical designer for better control of aberrations and allows one to develop compact and light-weight systems. The success of aspheric and freeform fabrication depends on capability of machine, techniques of metrology procedures and a feedback mechanism for optimizing the manufacturing process. An overview of manufacturing trends for precision optics is presented here with technological transformation from conventional to modern CNC based manufacturing which are suitable for aspheric and freeform fabrication.

1.1 Introduction

Fabrication of conventional optics is an old age technology where precision optical components comprises of variety of spherical lenses, various types of prisms, windows, wedge plates are used due to ease in manufacturing [1]. Optical design using these conventional geometries comprises more number of optical elements to achieve better performance. The use of aspherical and freeform optical components in an optical system minimizes the number of optical components required to obtain a certain image quality [2]. Therefore, such an optical system needs less space, has less weight, and, as there are less optical surfaces involved, causes less absorption. In the conventional manufacturing, optics is being grinded and polishing using full aperture tooling which make the process limited to spherical and Plano surfaces [3]. But in the case of aspheric and freeform surfaces, the geometrical form is much complex in nature and require subaperture tooling to remove material zone wise in a predetermined fashion with corrective feedback from metrology. Presently the grinding and polishing of aspheric optics from diameter 5 to 350 mm can be achieved by 5–7

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axis CNC machines, which generate tool path directly from the designed parameters and drive the grinding/polishing tools accordingly [4]. However, the success of these fabrication techniques depends on the capabilities of metrology procedures [5, 6] and a feedback mechanism for optimizing the manufacturing process. The correction on the tool path is added by metrology on profilometer and interferometer in a close loop feedback.

1.2 Traditional Fabrication Process

Traditional fabrication process involves fabrication of conventional optics which is simple geometry to maintain its final form and finish of the order of sub wavelength order. Variety of optical materials are used for fabricating theses optics based on their optical characteristics viz. refractive index, Abbe numbers, transmission etc. for various application from UV to Infrared. These including various types of optical glasses, infrared materials viz, silicon, germanium, zinc sulphide, zinc selenide and metals etc. The main steps in the fabrication of optical components from rough blank include trepanning, curve generation, grinding, smoothing, polishing and centering and edging operations. During curve generation, circular blank is given a designed geometrical form with 1 mm oversize from the finished part. Grinding is done to remove the extra material. The subsurface damage during grinding is controlled by smoothing operation where final particles of abrasive are. The polishing operation involves the full aperture polishing of grinded surface to maintain its final form error of the order of 100 nm. Pitch polisher is used as a polishing tool with complimentary curvature to surface under polish. Various polishing material are used to polish optical components depends upon the materials. For most of the glasses, cerium oxide based polishing materials are used. For infrared materials, aluminum oxide or diamond based slurries as polishing materials are used. Surface form error can be measured using interferometric methods.

1.3 Computer Controlled Fabrication for Aspheric and Freeform Optics and Its Metrology

Present technological trend in the field of optical design and fabrication is towards the aspherical and free form surface which drastically reduces the size and number of component of the system and enhances the performance of the optical systems. The fabrication of such aspherical and freeform surfaces can be carried out using CNC optical grinding and polishing machines. The modern practices of optical fabrication are more efficient with computer controlled machines, more accurate with laser Interferometry and more varied with advanced metrology tool like CGH (Computer Generated Hologram) and SHS (Shack–Hartmann wavefront sensor) based sub aperture stitching. Since the surface finish required on the polished optical components is around 100 nm peak to valley. This can only be achieved by using CNC grinding machines. For the polishing process various technologies are available including Single Point Diamond Turning (SPDT) [6], Bonnet Polishing [7], Magneto rheological finishing [MRF] [8], and Ion Beam Figuring [9].

Bonnet polishing is one of the advantageous method, where bonnet as a subaperture tool can be used for polishing with less tooling marks as bonnet can be precessed from different side of the surface and averaging the tooling marks. The Bonnet tool traverses a predetermined tool path based on the geometrical properties of aspheric surface in the presence of polishing slurry. Bonnet tool can directly be used on the grinded aspheric surface for pre polishing using synchro-spiral and corrective polishing using raster run process to achieve required surface. Further less tool wear and tear cost make this process more economical even for less number of components. Surface form of the order of 60 nm and surface roughness of 3–5 nm is possible by using this technique. In addition to bonnet polishing, other polishing techniques include SPDT, which is prudently used for fabricating infrared optics, metals and other nonferrous and non-silicate materials in aspheric and diffractive shapes. To achieve high surface accuracy and low roughness MRF can be used as a post polishing process after SPDT and bonnet polishing. The polishing slurry coagulated in the presence of electromagnet and takes the local shape of aspheric or freeform surface for perfect matching and controlled material removal rate during sub-aperture correction. In the ion beam figuring process, a directed and controlled beam precisely remove the material using feedback metrology. Using this technology, very high surface accuracy with super finish surface (surface roughness of 0.3 nm) can be achieved (Fig. 1.1(g)).

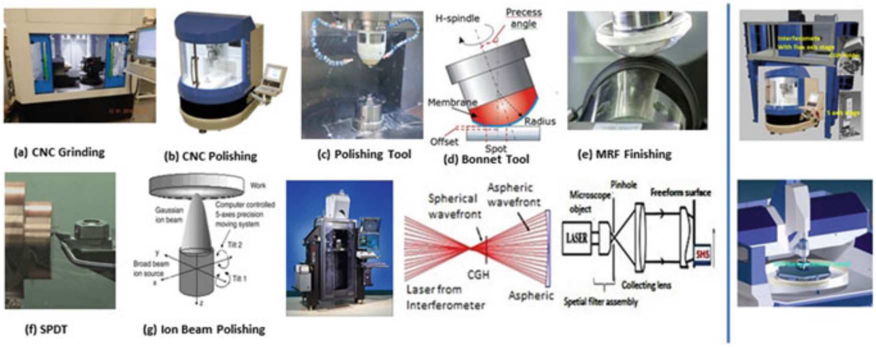

Fig. 1.1 Computer controlled fabrication machines and metrology

1.4 Conclusions

An overview of conventional and advance computer contolled fabrication techniques are presented for spherical, aspherical and complex freeform optics. Transformation of technological trends from conventional to aspheric and freeform fabrication is presented. Various CNC fabrication techniques are compared based on their process and requirement based on fabrication tolerances. With regards to precision optics testing, a large dynamic range as well as high accuracy can be extremely useful for insitu metrology (on-machine metrology) manufacturing process.

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