7. Processing (Grinding and Polishing)

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7.1 Introduction

7.1.1 Grinding and Polishing

Firstly, the nature and the goal of the three traditional manufacturing steps of optics, and the techniques applied there, should be pointed out.

The initial rough shape of the optics is provided by *generating*. The next step is a *fine grinding* operation which provides a surface shape as close as possible to the final geometry. Additionally, the roughness and subsurface damage left from generating have to be reduced. Finally, the optical surface is obtained by *polishing*. Sometimes, there is an additional polishing step called figuring which means corrective polishing to achieve the final surface shape.

The manufacturing steps introduced above can be performed by means of different material removal techniques. Generating is usually done by fixed abrasive grinding (Sect. 7.2.3). Until the 1970s, fine grinding was typically performed by loose abrasive grinding, sometimes also called lapping (Sect. 7.2.2). Then, especially in high-volume production, the fixed abrasive grinding tools and machines that were fairly expensive became common, too. Loose abrasive grinding is similar to the standard polishing process (Sect. 7.3.1). Nevertheless, there is an essential difference: loose abrasive grinding is dominated by mechanical material removal effects, whereas polishing is characterized by a combination of mechanical and chemical processes. In this context, *Brown* [7.1] created the model of the "chemical tooth".

The need for the distinction between the manufacturing steps of optics, and the techniques applied may be surprising because polished surfaces are glossy. On the other hand, the appearance of a typical ground surface is a mat finish due to the brittle fracture removal process. However, progress has recently been made in grinding as a finishing process. Now ground surfaces are obtainable whose appearance is similar to that of polished ones, although their character might be different; see the paragraph on "Shear Mode Grinding" in Sect. 7.2.3 below.

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7.1.2 Material Removal Rate

In order to be able to discuss "removal rates", a figure that is *system independent* is required. It seems to be a fairly difficult and uncertain task to reasonably compare material removal data on grinding or polishing regimes that work with quite different machine configurations, tool sizes and shapes. Nevertheless, the Preston equation, see [7.1] and its constant are tools which has proven quite helpful in overcoming such constraints.

The theoretical basis of material removal prediction was established in the 1920s by *Preston* [7.2], and was originally verified by loose abrasive grinding experiments. Later it was successfully applied to polishing and even fixed abrasive grinding [7.3]. The resulting equation,

$$\mathrm{d}h/\mathrm{d}t = cpv \ , \tag{7.1}$$

simply states that for a given process the rate of removal $\mathrm{d}h/\mathrm{d}t$ of a certain spot is the product of

- the pressure p at that spot,
- the relative velocity v between lap and workpiece at that spot, and
- a process constant c, which is a function of the workpiece material, lap material and slurry.

The Preston equation can be used to verify the proper functioning of a material removal process by monitoring the Preston constant, or in establishing advanced polishing machines [7.4]. It has to be pointed out that a high Preston constant does not automatically mean a high removal rate. When inherently different processes are compared, the pressures and velocities applied may differ tremendously. This becomes obvious when the Preston constant is compared with the *specific material removal rate* Q'_{w}, which is widely used in mechanics to characterize machining efficiency without concern for the intrinsic material removal mechanism. The *specific material removal rate* Q'_{w} is defined as

$$Q'_{\mathrm{w}} = a_{\mathrm{e}}\, v_{\mathrm{f}} \ , \tag{7.2}$$

with the depth of the cut a_{e} and the feed rate v_{f}.

Typical Preston coefficients and removal rates are given in Table 7.1.

7.1.3 Historical Background

According to *Parks* [7.7] the tradition of the fabrication of glass optics has existed for thousands of years. In those days, the philosophers of the cultures were quite aware of the lensing effect of spherical surfaces. Shiny surfaces were obtained by using loose abrasives containing corundum. The Romans were expert craftsmen in glass blowing and molding. Spectacles have been mentioned in the literature from 1300 A.D. onward.

Later, progress in the fabrication of optics was furthered by astronomers. Generally, the Dutchman *Lippershey* is given credit for making the first telescope