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Fabrication of small aspheric moulds using single point inclined axis grinding

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ABSTRACT

Single point inclined axis grinding techniques, including the wheel setting, wheel–workpiece interference, error source determination and compensation approaches, were studied to fabricate small aspheric moulds of high profile accuracy. The interference of a cylindrical grinding wheel with the workpiece was analysed and the criteria for selection of wheel geometry for avoiding the interference was proposed. The grinding process was performed with compensation focused on two major error sources, wheel setting error and wheel wear. The grinding results showed that the compensation approach was efficient and the developed grinding process was capable to generate small aspheric concave surfaces on tungsten carbide material with a profile error of smaller than 200 nm in PV value after two to three compensation cycles.

1. Introduction

Meso and micro optical components have been extensively used in a wide range of industrial applications, such as aerospace, optics, photonics and telecommunications, in the past decade [1,2]. With the further progress in modern industries, the requirement for high precision and the demand for mass production of those components are considerably increased [3,4]. As a result, a great research effort has been directed towards the development of high precision grinding processes for optical products, especially in aspheric form, in recent years [5,6]. For example, Chen et al. developed a parallel grinding protocol to generate micro aspheric mould inserts [7]. Cha et al. carried out a study of the optimisation of grinding conditions to improve surface roughness and profile accuracy of aspheric glass lenses for phone camera [8]. Han et al. specially designed an evolutionary grinding process for the fabrication of aspheric surfaces of a glass ceramic substrate [9]. Kim et al. developed a new sub-micron control algorithm in order to interpolate tool path in grinding and polishing aspheric surfaces [10]. To improve the profile accuracy through reducing the effects of tool fabrication and positioning errors and tool wear, several techniques for precise truing and dressing grinding wheels were developed [11–14], in-process measuring methods for form errors was employed [5,15] and a number of compensation approaches for tooling errors [16–18], tool wear [19–21], machine tool geometric error [22,23] and thermal effect [24,25] were proposed.

Nevertheless, there are still several key problems that need to be further addressed. For instance, the quality of truing and dressing of grinding wheels and tool wear had such significant effect on the profile accuracy of the ground surface [16–19], so that the compensation algorithm for such errors must be more efficient and rigorous. It was difficult to determine precisely the contact point of the arc grinding wheel during grinding [16], therefore, the accuracy of the compensated tool path was affected and the compensation efficiency in the next grinding cycle was compromised. Also, the error sources usually have interacted impact on the machined profile accuracy, the error should be compensated based on the existing machine [23] and on-machine measurement [15] should be encouraged in order to improve the compensation efficiency.

In this paper, we report a single point inclined axis nanogrinding protocol and its on-machine error compensation method. In this grinding protocol, a cylindrical superfine grinding wheel was selected and the grinding was carried out by integrating a rotary movement around *B*-axis into the conventionally used *X* and *Z* linear movements of a wheel. This enabled the single point contact

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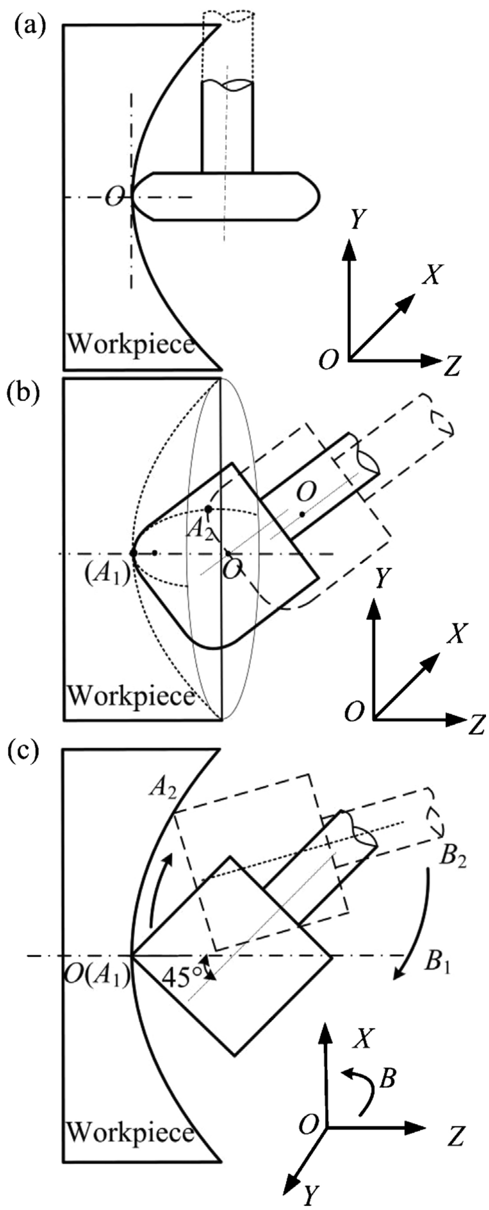

Fig. 1. Schematic illustration of three different grinding modes: (a) perpendicular mode, (b) inclined axis mode using an arc wheel and (c) single point inclined axis mode.

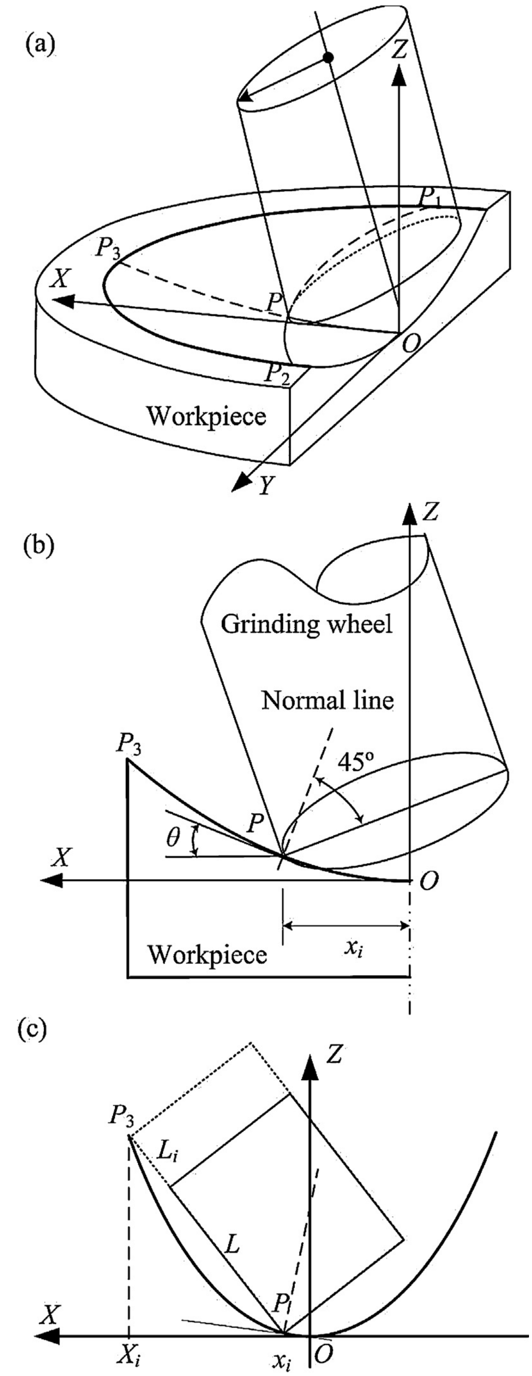

Fig. 2. Schematic illustration of (a) grinding positions of a cylindrical wheel and a concave surface (3D view), (b) the interference of the wheel and the surface along radial direction (cross-sectional view), and (c) the interference of the wheel and the surface along length direction (cross-sectional view).

during the entire grinding process. Error compensation approach was also developed, with the focus on centring error and tool wear error.

2. Set-up and characteristics of single point inclined axis grinding mode

As shown in Fig. 1(a), in conventional perpendicular arc envelope grinding, the wheel spindle is parallel to *Y*-axis, while the workpiece spindle is parallel to *Z*-axis. Because the rotational axis of the grinding wheel is perpendicular to that of the work-piece, the wheel will interfere with the workpiece if the sag of the concave surface being ground is too great. Therefore, this method is mainly used in machining aspheric surface of relatively large apertures. To avoid the interference, the wheel axis can be inclined, as shown in Fig. 1(b), where the wheel and work spindles intersect at a certain angle of normally 45°. In arc grinding shown in Fig. 1(a) and (b) the wheel arc is in contact with the workpiece, so the profile accuracy of the arc grinding wheel has significant effect on the profile accuracy of the ground surface. Also, the contact point is varied (moving along the arc) during arc grinding, so it is difficult to accurately estimate the wheel wear and hence lead to the inaccuracy in determining the tool path for the next grinding cycle.

To solve the abovementioned problems, in this work we proposed: (1) to adopt the inclined wheel spindle mode to effectively avoid interference between the wheel and the workpiece for grinding micro/meso optical surfaces, and (2) to use a cube corner wheel, instead of a arc corner wheel, in order to maintain a single contact point during grinding. Fig. 1(c) shows the set-up of the grinding