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# Three-dimensional profile stitching measurement for large aspheric surface during grinding process with sub-micron accuracy

Ping Yang*, Shi-wei Ye, Yun-feng Peng

*Department of Mechanical and Electrical Engineering, School of Aerospace Engineering, Xiamen University, China*

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ABSTRACT

A novel measurement method is proposed to realize three-dimensional (3D) profile stitching for large aspheric surface. The proposed method is based on the multiple sub-regions stitching technology applying a four-axis fixture and a commercial small-range profiler. The partition of sub-regions is due to the effective profiler's range and the characteristic parameters of aspheric surface, and the measurement for each sub-region within the profiler's range is achieved through the fixture to translate and rotate the aspheric surface. Then a stitching algorithm including the multi-body theory, the invariability of curvature radiuses and the least square principle is established to reconstruct the full 3D profile. Simulations of multiple sub-regions stitching for different aspheric surfaces are performed to predict the stitching accuracy of proposed method and analyze the influence of alignment errors in *Y* direction caused by the rotation error along *Z* direction ($\Delta\beta_{w,g}$). The stitching accuracy of proposed method is verified by measuring the 3D profile of an off-axis parabolic surface and an axisymmetric aspheric surface. The experimental standard deviations of stitching errors are 0.16 μm and 0.42 μm, which are less than the form errors of aspheric surface during grinding process. The results show that the proposed method achieves 3D profile stitching for large aspheric surface with sub-micron accuracy.



## 1. Introduction

Large aspheric surfaces have become widely utilized in various applications such as space optics and military field, because aspheric surfaces allow reducing the number of lenses and improving the performance in optical systems [1–3]. The precision profile measurement of aspheric surfaces in three dimensions is of importance to the manufacture and quality guarantee of a number of aspheric products. Especially, 3D profile measurement of these surfaces during the grinding process is not only the key assurance for aspheric parameters and form characterization of optics, but also improve the processing efficiency and form accuracy of polished aspheric surface [4,5].

The 3D profile measurement methods for large aspheric surfaces include optical interferometry and coordinate measurement technology, and many research works have been conducted in decades. Kang presented a method to achieve null test of aspheric 3D surface in a commercial interferometer by using computer generated holograms [6]. Zhao researched a new measurement method based on reconstruction algorithm and scanning 3D interferogram analysis to test the large aspheric surface [7]. Wiegmann proposed a virtual experiment for the accuracy assessment of the sub-aperture interferometric measurement of a synchrotron mirror involving several thousand sub-aperture topographies, and the reconstruction accuracies can be expected to be in the range of 100 nm [8]. However, the form errors of aspheric surfaces, which are generally with micron level during the grinding process, can't be detected by optical methods. The coordinate measurement technology based on the specialized profiler can achieve 3D profile measurement during grinding process. Jing studied a new 3D profile measurement method for off-axis parabolic mirrors using coordinate measurement machine and swing arm profiler during the grinding process [9]. Su conducted a research on the swing arm optical coordinate measurement machine, which is a profiler with a distance-measuring interferometric probe for in situ 3D measurement of the aspheric surfaces, and implemented a dual probe self-calibration mode for the swing arm optical coordinate measurement machine [10,11]. El-Hayek presented a compara-

* Corresponding author at: Xiamen University, Room 216, Science Building, No.422, Siming South Road, Siming District, Xiamen, Fujian 361005, China.
*E-mail address:* yangp@xmu.edu.cn (P. Yang).

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tive study of 3D measurement and form characterization for an aspheric lens using tactile and optical single scanning probing systems [12]. Long trace profilers are designed and developed to achieve slope measurement for large aspheric surfaces, and the full 3D form errors can be obtained by integral algorithm [13–15]. However, the swing-arm profilers and the long trace profilers utilized in coordinate measurement technology are usually self-designed and high cost of development. To improve the mentioned problems, we have published the preliminary work and investigated the optimal stitching planning method for two-dimensional profile of large aspheric optical surface [16]. Based on the proposed optimal stitching planning method, the stitching profile errors are in the range of ±1 μm and the standard deviations are less than 0.2 μm. In view of the stitching measurement results from 2D profile of large aspheric surface, the further research of 3D profile measurement is being developed to satisfy sub-micron measurement accuracy and economical cost.

In this paper, a measurement method based on multiple sub-regions stitching is proposed to measure the 3D profile of large aspheric surfaces. By applying a four-axis fixture and a commercial small-range profiler, the measurement for each sub-region is designed to achieve sub-micron accuracy. Then the corresponding stitching algorithm is developed to match the measured values of adjacent sub-regions and calculate the stitching accuracy affected by the alignment of aspheric surface. Based on the experimental results for measuring an off-axis parabolic surface and an axisymmetric aspheric surface, the stitching errors are almost with sub-micron level and far less than the form errors during the grinding process.

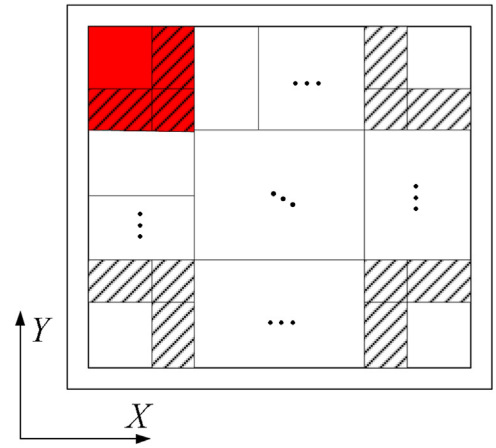


**Fig. 1.** Sub-regions partition for an aspheric surface.

## 2. Principle

The basic measurement principle of proposed sub-region stitching method utilizing the small range profiler is shown as the following steps.

(1) The large aspheric surface is divided into many sub-regions. Due to the limited range of profiler and the size of large aspheric optics, the number and size of sub-regions are determined to ensure that all the sub-regions can be detected by the profiler's single measurement. To achieve the sub-region stitching with high accuracy, the adjacent sub-regions have the overlap

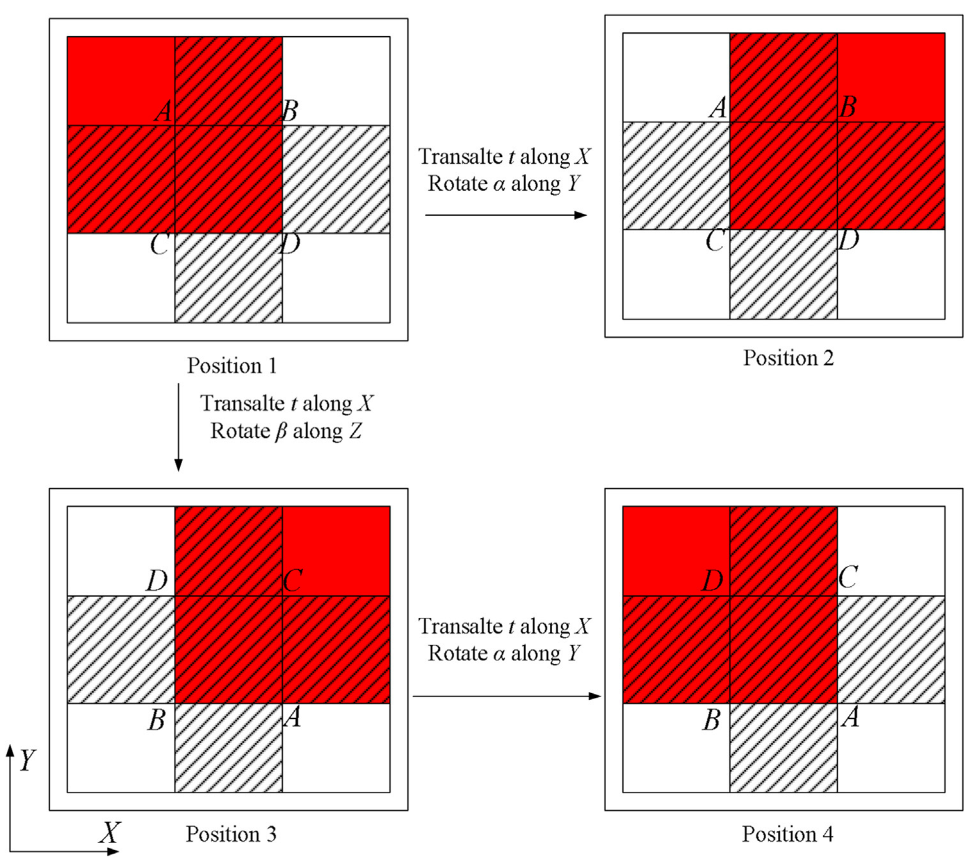


**Fig. 2.** Measurement process for four sub-regions.

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