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硕 士 学 位 论 文

磨削阶段大口径非球面光学元件拼接测量
技术研究

Research on stitching measurement technology for large
aspheric optics during grinding process

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摘 要

大口径非球面光学元件能校准像差, 提高像质, 减小光学系统的体积和重量, 并增加光学系统的可靠性, 因此其被广泛应用于航空航天、国防等先端科学技术领域。磨削阶段大口径非球面元件的面形检测是制约其推广应用的重要因素。坐标测量技术是实现磨削阶段光学元件面形检测的重要手段, 但是该技术在解决大口径、高陡度非球面元件的高精度测量上仍存在一系列技术问题需要解决, 比如自主开发的轮廓仪因成本高昂大多难以推广, 轮廓仪测头传感器有效测量行程不足, 待测工件的大尺寸相比轮廓仪运动量程受限, 多段拼接方法测量效率与精度不足且无法实现对非球面三维面形的测量等。针对上述问题, 本文对基于商用式小量程高精度轮廓仪的磨削阶段大口径非球面光学元件拼接测量技术进行了研究。论文的研究工作包括以下几部分。

(1) 提出轮廓线多段拼接测量前的分段方法, 并确定了分段方法中的参数。提出多段拼接算法, 并仿真分析算法中运动误差对拼接精度的影响。搭建三轴拼接辅助平台, 并用 Talysurf PGI 1240 轮廓仪对长条状非球面工件上两条不同轮廓线进行三段拼接的验证实验。实验结果表明, 两条轮廓线的全口径拼接误差标准偏差值分别为 $0.16\mu\text{m}$ 与 $0.14\mu\text{m}$ 。

(2) 将轮廓线拼接测量拓展至非球面三维面形拼接, 提出基于四轴运动平台的子区域拼接测量方法, 建立了相应的子区域拼接算法, 并仿真分析绕 Z 轴旋转误差对三维面形拼接精度的影响。在三轴拼接辅助平台上增设绕 Z 轴旋转平台, 并分别对离轴抛物面工件和轴对称非球面工件进行三维面形拼接测量的实验验证。实验结果表明, 两块非球面工件的全口径拼接误差标准偏差值分别为 $0.21\mu\text{m}$ 与 $0.42\mu\text{m}$ 。

(3) 本文开发了非球面拼接测量软件系统, 包括轮廓线拼接测量模块与三维轮廓拼接测量模块, 便于测量数据处理。

关键词: 大口径非球面光学元件; 拼接测量; 亚微米级精度

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Abstract

Large aspheric optical elements are extensively applied in aerospace and military field, because large aspheric optics can calibrate aberrations, improve image quality, reduce the volume and weight of the optical system, and increase the reliability of the optical system. The surface measurement of large aspheric optics during the grinding process is a key influence factor for its application. The coordinate measurement technology is an important way to realize the surface measurement of large aspheric optics during the grinding process. However, there are still a series of technical problems when the coordinate measurement technology is applied to achieve surface measurement for large aperture and high steep optics: the self-designed profilers are difficult to be popularized due to the high cost, the measurement range of profiler sensor is limited, the moving range of profiler is limited compared to the size of aspheric optics, the measurement efficiency and stitching accuracy of existing multi-segment stitching measurement technology are insufficient and the technology can't realize three-dimensional surface measurement. To solve the mentioned problems, the stitching measurement technology based on small-range commercial profiler is proposed to achieve high-precision surface measurement for large aspheric optics during the grinding process. The research work of this paper includes the following parts.

(1) To propose the segment planning method before measuring the aspheric optics, determine the parameters of the segment planning method, present the multi-segments stitching algorithm, and analyze the influence of motion errors affecting the stitching accuracy through simulations. Then to build the experimental setup with Talysurf PGI 1240 and self-developed three-axis fixture. Three-segments stitching is applied to measure two different aspheric profile lines to verify the proposed multi-segments stitching technology. The experimental results indicate that the standard deviations of stitching errors are $0.16\mu\text{m}$ and $0.14\mu\text{m}$, respectively.

(2) To expand the multi-segments stitching technology to three-dimensional surface stitching technology, propose the sub-region stitching measurement method based on the four-axis fixture, build the corresponding sub-regions stitching algorithm, and analyze the influence of the rotation error along Z axis. Then to add a rotation stage along Z axis to the three-axis stitching fixture. The off-axis parabolic surface and axisymmetric aspheric surface are applied for experiments to verify the sub-region stitching technology. The experimental results indicate that the standard deviations of stitching errors are $0.21\mu\text{m}$ and $0.42\mu\text{m}$, respectively.

(3) To develop the software system of stitching measurement technology for aspheric optics. The software system, including the multi-segments stitching module and the sub-region stitching module, is convenient for data processing.

Key words: Large aspheric optical surface; stitching measurement; sub-micron accuracy.

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