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博 士 学 位 论 文

高精度楔形非球面制造及测量技术研究

Research on High Precision Machining and Measuring Technology of Wedge Aspheric Surface

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摘 要

非球面光学元件具有矫正像差、简化系统、提高光学系统精度优点。当前，光学非球面器件的使用主要受到其加工精度、表面质量和制造成本的限制。精密数控磨削加工技术克服了原有传统非球面器件加工中人为因素决定工件精度、加工效率、重复性差的缺点，是一种加工光学非球面零件的新方法。

本文针对光学非球面的加工机理，提出了多种改善加工效率、提高加工精度的加工与测量方法。设计并实现了高精度非球面制造及测量系统软件模块：完成非球面磨削加工的工件安装定位、加工轨迹规划、加工精度影响因素控制整套流程；砂轮加工磨削线速度及进给速度对元件加工精度的影响；不同非球面元件表面方程的数学建模及应用；加工工具均匀磨损控制及工件均匀磨削量控制方法。

针对非球面磨削加工系统误差补偿要求，提出使用方便、数据易于补偿的点对多点在线测量技术；建立加工中系统误差分离模型；研究砂轮半径误差和砂轮主轴长度误差的分离技术；解决补偿加工中不同误差成分的数据处理；完成砂轮半径数据及主轴长度数据更新及系统误差补偿数据准备。

研究平面、圆弧、球面金刚石砂轮对加工工件形状精度、尺寸精度及机床误差的影响；砂轮在各加工点磨削线速度的不同、砂轮在非球面各区域停留时间的不同造成了砂轮在各加工点磨削量差异的影响；根据非球面磨削加工要求，设计并实现了工具修整系统，该系统实现了圆弧砂轮包络修整方法及修整后的形状精度测量。

本文主要创新点有：

1、提出在3轴数控磨床上实现广义楔形非球面的新型加工方法。针对旋转叠加非球面的表面特征，提出适用于楔形非球面加工表面复原建模，表面点测量及加工轨迹规划的方法。

2、提出非球面磨削加工中工件均匀磨削量和加工工具均匀磨损控制方法。针对砂轮各加工点磨削线速度及停留时间不同，建立砂轮进给速度、磨削线速度、磨削面积、砂轮停留时间的控制模型；分析砂轮磨削线速度、进给速度及砂轮磨损情况，提出控制砂轮均匀磨损的方法，解决非球面元件加工点均一磨削量和提

延长了砂轮使用寿命问题。

3、提出非球面误差补偿加工系统误差分离方法。从误差数据中分离出砂轮半径误差及主轴长度误差所引起的系统误差，更新砂轮半径数据及主轴长度数据，完成补偿加工数据的准备。

4、提出点对多点无线通信的机床在线检测方法。将机床在线检测数据，机床加工参数，环境检测数据，通过无线通讯接口实现数据交换。减少外围加工因素对加工精度的影响。

关键词：非球面加工；精密检测；误差补偿；加工精度；金刚石砂轮；

Abstract

With the development of national defense industry, aerospace industry and civil optical technology, various kinds of high performance aspheric optical lens have been developed and widely used in the high performance optical systems. Compared with the spherical optical accessory, the aspheric lens can correct aberration, simplify system structure and improve the accuracy of system. At present, many factors hinder the application of aspheric lens, such as machining accuracy, surface quality and manufacturing cost. However, the manufacture of aspheric lens also confronted with the problem to improve the machine accuracy and efficiency. Among various machining methods of aspheric surface, the precision grinding is the main method to determine the form accuracy, roughness and surface quality, which can obtain high accuracy and glabrous surface. The precision numerical control grinding is a new technology for optical aspheric machining. Comparing with the traditional aspheric surface machining technology, it has the advantages of good accuracy, good efficiency, and good product repeatability. It can also produce aspheric in batch and reduce the cost.

Aiming at the machining principle of aspheric optical lens, a series of machining and measurement methods have been put forward to improve the machining accuracy and efficiency. Base on these technologies, the control system of high precision aspheric machining and measurement has been realized. The research emphases include the installation and position of aspheric workpiece in grinding procedure, grinding locus planning, accuracy influence of wheel grinding linear speed and feed speed, mathematics model and application of various aspheric surface formula, wheel uniform wear and removal quantity control method.

In this paper, a point-to-multipoint online measurement technology has been put forward for the error compensation requirement of aspheric grinding system. It builds the model to analyze the reason of error come into being, and then separates system

error of spindle and wheel radius error from machining error data. Finally, it updates the system parameters, and prepares the error compensate data.

According to different machining object, different types of wheel were used. They are the plane, arc and sphere wheel. Besides the effect of the form accuracy, the dimensional accuracy of the grinding wheel and the machine error to the process accuracy, the grinding linear velocity of the grinding wheel and its feed velocity are vital factors that affecting the machining accuracy. According to the requirement of aspheric grinding, a wheel truing system has been designed to realize the function of truing arc wheel and measuring the form accuracy of wheel.

According to the usage condition of different wheels, some experiments have been done to verify the new machining and measuring methods, the experiments including wheel truing and measurement experiment, inclined plane machining experiment and wedge aspheric machining experiment.

Main innovation as follows:

1. The paper presents a new machining method of wedge aspheric in three linear axis numerical control grinding machine. Aiming at the surface characteristics of rotation and superposition of aspheric, a mathematics model to recover the surface has been built. Moreover, the applicability of the machining tools, measurement method and type of workpiece have been analyzed, and the locus planning methods of wedge aspheric measuring and machining have been put forward.

2. The paper put forward a control method to control the uniform removal quantity in wedge aspheric grinding. Aiming at the difference of machining linear speed and machining time length between different wheel machining point, this new method control the feed speed, linear speed and machining time length of machining. It solves the problem of removal quantity inconsistency between different points of workpiece, which achieves the goal of control machining error and improves machining accuracy.

3. The presents a point-to-multipoint online measurement system of machine. The system embodies the principles of processes concentrated and benchmark coincidence. It provides the function of online measurement to an ordinary machine. And it can transfer the data to the server wireless. The system doesn’t need to modify original

machine and cabling, it can improve machining accuracy and efficiency, and it has no bad influence to the original machine.

4. The paper put forward a machining error processing method of aspheric. The old error compensate method superpose the error data to ideal aspheric surface. However the new method builds the model to analyze the reason of error come into being, it can act as separating the system error of spindle and wheel radius error from machining error data, updating the radius and spindle length data, and preparing the error compensate data. It can improve machining accuracy more.

The paper put forward a wheel uniform wear control method in wedge aspheric grinding. Aiming at the influence of wheel wear condition, a method has been put forward to control the wear of wheel. It solves the problem of wear condition inconsistency between different points of wheel, which prolongs the life of wheel and improves machining accuracy in aspheric machining.

Keywords: Aspheric Machining; Precision Measurement; Error Compensation; Machining Accuracy; Diamond Wheel

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