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碩 士 論 文

使用掃描式測頭之五軸工具機雙旋轉軸幾何誤差同步量測系統

Synchronous measurement system for geometric errors of double rotary axes of five-axis machine tools using scanning probe

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摘要

本論文以使用掃描式測頭為重點，針對五軸工具機之雙旋轉軸提出一套幾何誤差量測系統，掃描式測頭與較泛用的接觸式測頭相比能夠由連續的訊號觸發得到方向的幾何角度數值以獲得更多的量測資訊，有利於同時解析大量的誤差項。此系統以福裕事業開發的 Uni5X-400 搖籃式五軸工具機為實驗載具以掃描式測頭量測校正球與方塊的幾何資訊用以解析誤差項，工具機的誤差來源分為動態誤差與準靜態誤差，其中準靜態誤差類別內的幾何誤差會顯著影響加工精度，根據國際標準規範幾何誤差又可分為安裝誤差與運動誤差並發生於線性軸與旋轉軸上，以往眾多學者的研究通常僅針對單軸的幾何誤差做同步解析，或者多軸之安裝誤差，忽略了雙軸同時做動的誤差耦合影響或相異驅動位置下的運動誤差值，而本論文開發之量測系統能夠透過量測校正球與方塊以同時解析雙旋轉軸之二十項安裝誤差與運動誤差，且以安裝方便、快速量測、價格便宜為優點。

量測系統開發過程首先針對工具機內部之搖籃構型以齊次座標轉換矩陣建模，能夠表示工具機中各軸之間的相對運動，接著透過正向運動學推導測頭、校正球與方塊在空間中的位置，以及方塊各平面的法向量方向，並且分為理想不含誤差與實際在幾何誤差影響下的情況。再由逆向運動學計算校正球與方塊在該位置下的理想與實際控制器驅動值並相減，得出體積誤差、體積偏擺與幾何誤差的關係式，最後針對實驗假設修正並整理為矩陣方程組套用最小平方法求解，再以隨機變數代入驗證系統的正確性。實際實驗後的量測結果與先代學長開發之系統計算的結果以及擬合圓評估之幾何誤差數值做交叉比對，三種方法得出的結果大致相符以驗證此方法的可行性。

關鍵字：五軸工具機、旋轉軸、幾何誤差、掃描式測頭、雙軸同動

ABSTRACT

Synchronous measurement system for geometric errors of double rotary axes of five-axis machine tools using scanning probe

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SUMMARY

This paper proposes a geometric error measurement system for the dual rotation axes of five-axis machine tools, focusing on the scanning probe. Unlike contact probes, the scanning probe uses continuous signals to gather more measurement information, aiding in the simultaneous analysis of numerous error terms. The system uses the Uni5X-400 cradle-type five-axis machine tool developed by Fuyu Business. It measures the geometric information of correction balls and blocks to analyze error sources, divided into dynamic and quasi-static errors, with geometric errors in the latter significantly affecting processing accuracy. Geometric errors are categorized into installation and motion errors on linear and rotating axes. Previous research often analyzed errors in isolation, ignoring the coupling effects of simultaneous dual-axis movement. This system, however, can simultaneously analyze twenty installation and motion errors of dual rotation axes, offering easy installation, fast measurement, and low cost.

The system's development involved using a homogeneous coordinate transformation matrix to model the machine tool's cradle configuration, representing the relative motion between various axes. Forward kinematics related the probe and calibration ball to the spatial position of the block and the normal vector direction of each block plane, considering ideal and actual situations with geometric errors. Inverse kinematics calculations corrected ideal and actual controller drive values to determine the relationship between volume error, deflection, and geometric error. Finally, the system's equations were solved using the least squares method, with random variables verifying correctness. Experimental results were consistent with previous studies and fitted circle evaluations, validating the system's feasibility.

Keywords: Five-axis machine tool, rotary axis, geometric error, scanning probe, dual-axis synchronized motion.