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# 非接觸式線雷射感測器之傘齒輪自動化量測

# Automated Measurement of Bevel Gears Using a Non-Contact Line Laser Sensor

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## 中文摘要

隨著精密製造技術的演進，齒輪幾何品質對高精度與高負載傳動系統的影響日益關鍵，尤其傘齒輪因其結構複雜，對量測精度要求更高。傳統接觸式量測方式不僅程序繁瑣，易受人為操作影響，亦難以整合於自動化生產線中。

本研究提出一套基於非接觸式線雷射感測器之自動化量測系統，整合基恩斯（KEYENCE）線雷射、海德漢（Heidenhain）iTNC530控制器與以Visual C#開發之人機介面，並搭載於百德五軸工具機UX300。其中一組角度軸用於感測器對正，實際量測時採用 $X$ 、$Y$ 和 $Z$ 與工件旋轉軸 $C$ 四軸同動控制架構。

系統可自動完成節距與齒面誤差量測，搭配座標轉換與資料擷取演算法，有效排除對位與機構誤差。誤差評估依據DIN3965標準進行，包含單齒節距誤差、節距誤差範圍、累積誤差、徑向跳動誤差與齒面法向誤差等指標。實驗結果顯示，本自動化量測系統不僅能顯著縮短量測時間，亦具備與高階商用量測設備相當之精度與一致性，適用於傘齒輪製程中的品質監控與驗證需求。本研究成果可作為未來齒輪生產線導入智慧化自動量測模組之基礎，促進製程效率與生產品質全面提升。

關鍵字：傘齒輪量測、非接觸式量測、線雷射感測器、自動化量測、海德漢控制器

# Abstract

With the advancement of precision manufacturing technologies, the geometric quality of gears has become increasingly critical for high-precision and high-load transmission systems. In particular, spiral bevel gears—with their complex geometry—demand higher measurement accuracy. Traditional contact-based measurement methods are not only time-consuming and prone to human error, but also difficult to integrate into automated production lines.

This study proposes an automated measurement system based on a non-contact line laser sensor, integrating a KEYENCE laser sensor, a Heidenhain iTNC530 controller, and a custom-developed Visual C# human-machine interface, mounted on a Buffalo UX300 five-axis machine tool. One of the rotary axes is used for sensor alignment, while actual measurement is performed using a four-axis simultaneous control involving the X, Y, Z axes and the workpiece rotary axis (C-axis).

The system automatically performs pitch and flank error measurements, incorporating coordinate transformation and data acquisition algorithms to effectively eliminate alignment and mechanical deviations. Error evaluation follows the DIN 3965 standard, covering indicators such as single pitch deviation, total pitch variation, cumulative pitch error, radial runout, and normal flank deviations.

Experimental results demonstrate that the proposed system significantly reduces measurement time while achieving precision and consistency comparable to high-end commercial equipment. This automated solution is suitable for quality inspection and process verification in spiral bevel gear manufacturing and may serve as a foundation for future intelligent in-line gear measurement modules, enhancing production efficiency and product quality.

Keywords: Bevel Gear Measurement, Non-contact Measurement, Line Laser Sensor, Automated Measurement, Heidenhain Controller