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研磨機的載台振動構造

關鍵字：超音波振動輔助磨削、綠能製造、智慧製造、節能減碳、難加工材料磨削

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摘要

本專利技術主要針對現有超音波振動輔助磨削系統在實際應用上的不足加以改良。突破了傳統系統體積龐大、安裝不便、頻率無法調整以及能耗過高等問題。本研究所研發之節能高效率超音波振動輔助磨削系統，採用智慧化建模方式優化至振系統幾何結構，使其在超音波最低頻率20 kHz 下即可達到最大系統振幅量。採用外掛式模組化設計，可單獨推廣與銷售，並能輕易安裝於國內外各類磨削工具機上使用，大幅提升原有磨削工具機加工性能與效益，無需額外投入大量資金重新購置超音波振動輔助磨削專用工具機。此外，本技術具備完整的理論基礎與實務應用價值，特別適用於加工高硬度合金等特殊材料。其應用可有效提升磨削效率，協助製造業降低碳排放、達成碳中和目標，並對相關產業的綠色製造技術發展作出貢獻。

本研發專利主要創新價值重點

A 國際首創：研發獨立式模組、解決體積龐大、不易架設與耗能痛點。

B 兼融性強：可輕易結合搭配在國內外多種市售磨削工具機上使用。

C 效能提升：可大幅提升原有磨削工具機性能，提升難削材的磨削效益。

D 綠能製造：使用最低的超音波頻率達成最高的振幅，並可兼具降低製程耗電量與碳排放。

E 產業推廣：本系統具備模組化、標準化與商品化特性，適合量產與跨產業推廣，可廣泛應用於精密製造、航太、能源、半導體及醫療器材等高端產業。

近年來發展的超音波振動輔助精密磨削技術，係將超音波加工與振動輔助加工的優勢加以結合，用於高硬度材料之精密加工。然而，目前超音波振動輔助技術多集中於切削加工，較少延伸至磨削領域。隨著新材料不斷湧現，以及對產品性能與品質要求的提升，磨削技術已成為精密製造的重要焦點。然而，有關超音波振動輔助磨削的研究仍相對稀少。目前國際上僅有少數原型系統，多存在體積龐大、結構複雜、耗能高且振動效率低等問題，實用性與便利性不足，距離實際產業應用仍有落差。本專利研發的核心創新在於：運用智慧化建模優化致振系統，開發出全球首創可於超音波最低頻率20 kHz下達成最大振幅的系統，並大幅降低能耗，展現極高的產業應用潛力。

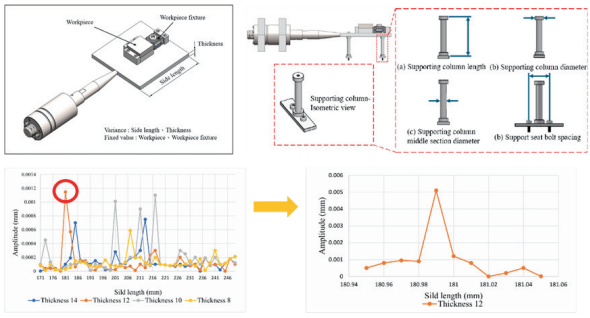

圖1. 系統致振平台與撓性支撐柱系統幾何結構CAE模態最佳化設計與分析。

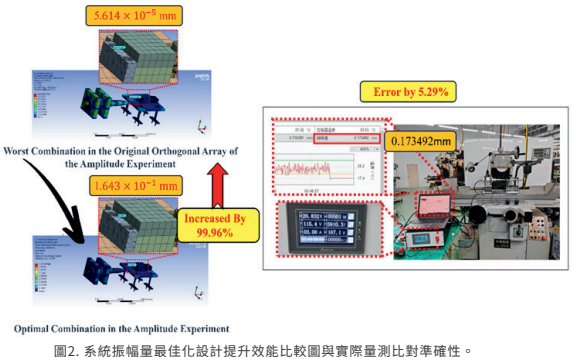

圖2. 系統振幅量最佳化設計提升效能比較圖與實際量測比對準確性。

Axial	Average Simulated Value(mm)	Average Measured Value(mm)	Average Error
X-Axis	0.139270	0.133753	4.12%
Y-Axis	0.082611	0.078211	5.62%

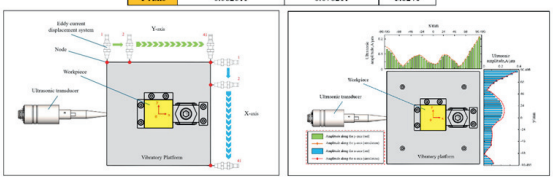

圖3. 系統致振平台振幅量分析與實際量測位置與數值比對圖。

功能與實用性

本專利技術旨在開發一套低耗能且高效能之超音波振動輔助磨削系統。經實驗驗證，本專利技術相較於傳統磨削，在鈦合金、工具鋼與中碳鋼加工中，分別可降低磨削力達 90.87%、78.36%、64.6%，磨削溫度下降 8.83%、7.62%、12.2%，表面粗糙度提升 32.64%、16.35%、19.79%，同時減少碳排放 70%、42.85%、66.67%，並降低電功率使用 0.92%、1.14%、1.26%。綜上所述，本專利技術不僅成功突破傳統超音波振動輔助磨削系統在體積、能耗與架設不便等限制，並以實驗數據證實其能顯著提升磨削效益、降低能源耗損與碳排放，符合節能減碳與綠色製造之發展需求，具高度產業應用價值與創新性。

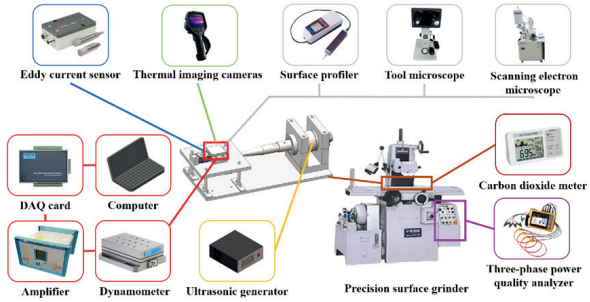

圖4. 整體系統量測設備圖。

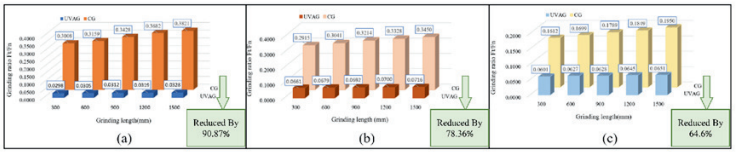

圖5. 不同磨削方式磨削不同特性材料之磨削力比較圖。

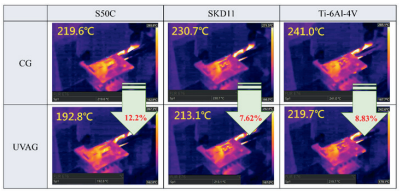

圖6. 熱像儀拍攝磨削溫度比較圖。

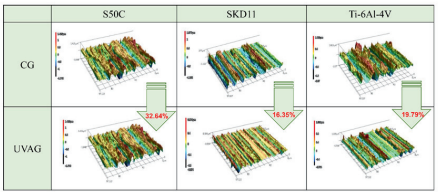

圖7. 雷射顯微鏡拍攝磨削表面粗糙度比較圖。

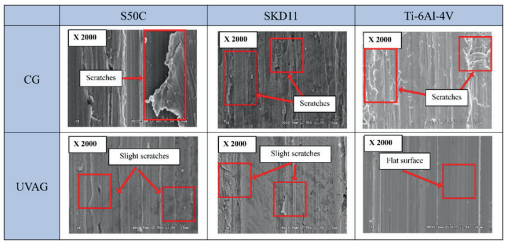

圖8. 不同磨削方式磨削不同特性材料之磨削表面形貌比較圖。

圖9. 使用系統磨削節能減碳效益比較圖。

商品化程度

近年來，硬質合金與特殊材料的精密加工已成為產業急需突破的瓶頸。其中，超音波振動輔助切削被證實能有效提升加工效益，並已受到先進國家重視與投入研發。因此，開發可應用於磨削的超音波振動輔助系統具迫切產業需求。本專利研發之低耗能高效益超音波振動輔助磨削系統，已完成原型設計與商品化，採外掛式模組化架構，可輕易搭配各類磨削工具機使用，無需新增專用設備，即可大幅提升原有機台對硬質材料的加工性能與效益。實際驗證顯示本系統能顯著降低磨削力、溫度與能耗，同時改善表面粗糙度與形貌品質，並有效減少碳排放，符合綠色製造與節能減碳的發展目標。對於航太與半導體等高度依賴硬質合金磨削的產業，本專利技術具高度實用性與迫切應用價值，並可協助產業達成淨零排放目標。

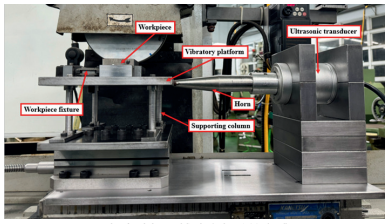

圖10. 超音波振動輔助磨削系統實體圖。

圖11. 本團隊研發之綠色製造製技術與設備獲廠商積極熱烈洽詢。

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Patent Certificate Number: Invention No. I893870

STAGE VIBRATING DEVICE of GRINDING MACHINE

Keywords：Ultrasonic Vibration-Assisted Grinding(UVAG), Green Energy Manufacturing, Smart Manufacturing, Energy Saving and Carbon Reduction, Grinding of Difficult-to-Machine Materials

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Abstract

This patented technology addresses the shortcomings of existing ultrasonic vibration-assisted grinding (UVAG) systems in practical applications. It overcomes traditional limitations such as excessive system size, installation difficulties, fixed frequency operation, and high energy consumption. With a modular plug-in design, the system can be marketed and sold independently, and can be easily installed on a wide range of domestic and international grinding machines. This significantly enhances the machining performance and efficiency of existing equipment without requiring substantial investment in new, dedicated UVAG machines.

Key Innovative Values of the Patent Development:

A **World’ s First**：**Development of an independent modular system that resolves the issues of bulkiness, installation challenges, and high energy consumption.**

B **High Compatibility**：**Easily integrated with a wide variety of commercially available grinding machines worldwide.**

C **Performance Enhancement**：**Substantially improves the performance of existing grinding machines, particularly in the processing of difficult-to-machine materials.**

D **Green Manufacturing**：**Achieves maximum vibration amplitude at the lowest ultrasonic frequency, reducing power consumption and carbon emissions during the machining process.**

E **Industrial Promotion**：**Featuring modularization, standardization, and commercialization, the system is suitable for mass production and cross-industry applications, including precision manufacturing, aerospace, energy, semiconductors, and medical devices.**

In recent years, ultrasonic vibration-assisted precision grinding technology has emerged by integrating the advantages of Ultrasonic Machining and Vibration-Assisted Machining for precision processing of high-hardness materials. Nevertheless, research on UVAG remains relatively limited. Existing international prototypes are often bulky, structurally complex, energy-intensive, and inefficient, with insufficient practicality for industrial adoption. The core innovation of this patented development lies in the application of intelligent modeling to optimize the vibration system, resulting in the world’ s first system capable of achieving maximum amplitude at the minimum ultrasonic frequency of 20 kHz while significantly reducing energy consumption. This system has substantial potential for industrial application.

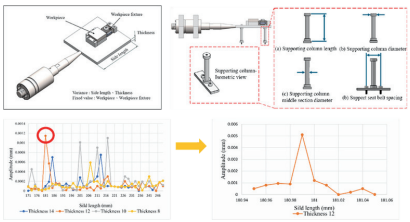

Figure 1. Modal optimization of vibration platform and compliant support column geometry (CAE analysis).

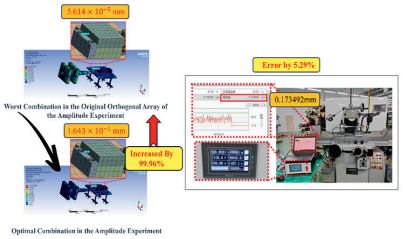

Figure 2. Optimized vibration amplitude design: performance enhancement and experimental validation.

Axial	Average Simulated Value(mm)	Average Measured Value(mm)	Average Error
X-Axis	0.139270	0.133753	4.12%
Y-Axis	0.082611	0.078211	5.62%

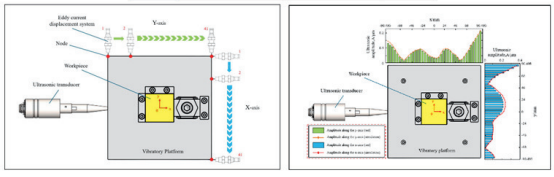

Figure 3. Comparative analysis of simulated and measured vibration amplitudes at selected positions.

Functionality and Practicality

The purpose of this patented technology is to develop a low-energy-consumption and high-performance ultrasonic vibration-assisted grinding system. Experimental validation demonstrated that, compared with conventional grinding (CG), the proposed technology achieved reductions in grinding forces of 90.87% for Ti-6Al-4V, 78.36% for SKD11, and 64.6% for S50C. Grinding temperatures decreased by 8.83%, 7.62%, and 12.2%, respectively, while surface roughness improved by 32.64%, 16.35%, and 19.79%. Moreover, carbon emissions were reduced by 70%, 42.85%, and 66.67%, alongside decreases in power consumption of 0.92%, 1.14%, and 1.26%.significant improvements in grinding efficiency, energy reduction, and carbon emission control. It aligns with the goals of energy conservation, carbon neutrality, and green manufacturing, while offering high industrial applicability and innovation.

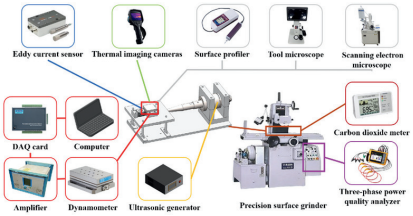

Figure 4. Experimental setup for system measurement.

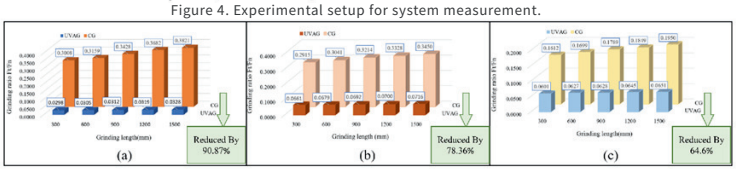

Figure 5. Comparative analysis of grinding forces for different materials under various grinding methods.

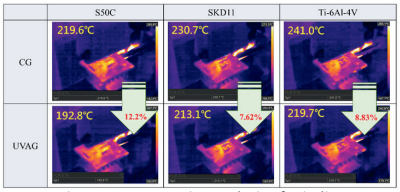

Figure 6. Comparative analysis of grinding temperatures using infrared thermography.

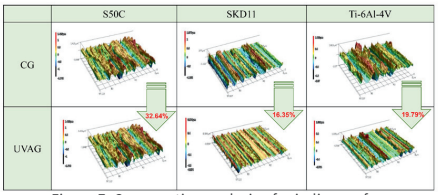

Figure 7. Comparative analysis of grinding surface roughness using laser microscopy.

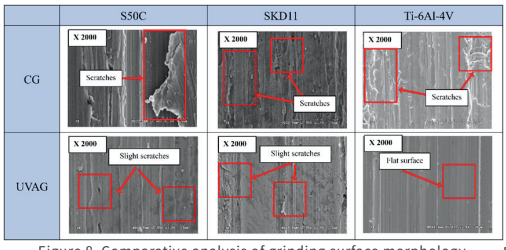

Figure 8. Comparative analysis of grinding surface morphology for different materials under various grinding methods.

Figure 9. Comparative analysis of energy-saving and carbon-reduction benefits of the system.

Commercialization Readiness

In recent years, the precision machining of hard alloys and specialized materials has become a critical industrial bottleneck. Ultrasonic vibration-assisted cutting has been shown to effectively enhance machining performance and has attracted significant investment from advanced economies. The patented low-energy, high-efficiency UVAG system developed in this study has completed both prototype design and commercialization. Its modular plug-in architecture allows seamless integration with a wide range of grinding machines without the need for additional dedicated equipment, substantially improving the machining performance of existing tools for hard materials. Experimental validation in grinding applications for Ti-6Al-4V, SKD11, and S50C confirmed significant reductions in grinding force, temperature, and energy consumption, along with improvements in surface roughness, morphology, and carbon reduction. This aligns with the development goals of green manufacturing and energy conservation.

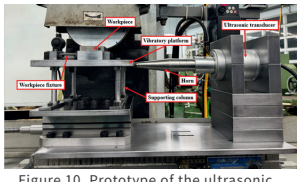

Figure 10. Prototype of the ultrasonic vibration-assisted grinding system.

Figure 11. Industrial engagement with the developed green manufacturing technologies and equipment.