Smart Micro-milling: Automated Tool Wear Measurement and Machine Learning for Wear Prediction

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KEYWORDS: Micro-milling, machine vision, machine learning, tool condition monitoring

Micro milling is a precision manufacturing process vital for fabricating micro-scale features (≤1mm), where tool wear significantly affects machining accuracy and surface quality. Real-time monitoring of tool conditions is essential to ensure process stability and prevent premature tool failure. This research introduces an advanced tool condition monitoring system that integrates machine vision, machine learning, and sensor fusion to predict tool wear in micro milling.

A machine-mounted microscope is employed in an indigenously developed micro-milling machine for real-time acquisition of high-resolution tool images. Image processing techniques are used to correct for minor variations in tool positioning, enabling automated measurement of tool wear. The wear data are then used to train a machine learning model that predicts the tool's condition.

The system also integrates sensor fusion, combining data from cutting force, vibration, and stage torque sensors to enhance the accuracy of instantaneous tool wear predictions. The predictive model is deployed on a remote high-performance computer and communicates in real-time via OPC UA, ensuring seamless tool condition monitoring and feedback.

This integration of machine vision and predictive analytics enhances the micro-milling process by offering a robust solution for proactive tool management, reducing downtime, and improving both machining efficiency and product quality.