

AI-based Instability Monitoring and Process Optimization for Electrical Discharge Machining

March 2026

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Thesis Abstract

No. _____

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Thesis Title AI-based Instability Monitoring and Process Optimization for Electrical Discharge Machining			
Thesis Summary Electrical discharge machining (EDM) is a non-contact manufacturing process that enables the fabrication of complex geometries in electrically conductive materials independent of their mechanical hardness. This makes EDM particularly suitable for machining hard and brittle materials such as cobalt-bonded tungsten carbide (WC-Co), which are widely used in micro-parts, precision molds, and high-performance tooling. However, EDM performance, especially in micro-scale and deep-hole machining, is strongly constrained by discharge instability caused by debris accumulation within the inter-electrode gap. Inadequate debris removal leads to frequent tool retraction, unstable discharge conditions, reduced material removal rate, and increased surface defects. Addressing these challenges requires an understanding of discharge dynamics that cannot be fully captured through conventional static optimization alone. Chapter 1 presents the motivation and objectives of this research. Chapter 2 reviews EDM fundamentals, the machining characteristics of WC-Co, powder-mixed and rotary EDM, and recent advancements in sensing and machine learning assisted manufacturing. Chapter 3 experimentally investigates the effects of adding conductive, semiconductive, and insulating powders to the dielectric during micro-EDM of WC-Co. Although powder addition enhances short-hole machining performance, severe debris accumulation and instability occur during deep micro-hole machining. The roles of tool rotation and statistical optimization are also examined, but these approaches are insufficient to capture the dynamic evolution of instability. Chapter 4 analyzes electrical discharge waveforms using artificial intelligence (AI)-based methods to identify discharge characteristics associated with instability. Heuristic detection and classification, together with Random Forest and XGBoost models, are employed to extract key features. Subsequently, a low-latency one-dimensional convolutional neural network (1D-CNN) is developed for direct waveform-based discharge classification. Chapter 5 investigates the dynamic nature of instability through phase-segmented and temporal analysis to evaluate the influence of tool rotation rate. A temporal convolutional network (TCN) is developed for early instability forecasting, and machine-learning-based models are proposed to predict the evolution of machined profiles from waveform features. A control system framework is proposed, and its offline validation is performed. Chapter 6 presents the overall conclusions of this research. This study demonstrates that integrating waveform-level monitoring with an auxiliary, adaptive tool-rotation strategy enables a robust, generalizable framework for improving machining stability.			