Current and Future Challenges of Hybrid Electrochemical-Mechanical Machining Process for Micro- and Nano-Manufacturing

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Abstract As industries like electronics, aerospace, and biomedical engineering evolve, the demand for intricate, precise components has surged. Traditional machining methods often fall short in the realm of micro- and nano-manufacturing, necessitating the development of innovative techniques like the Hybrid Electrochemical-Mechanical Machining (HEMM). HEMM synergistically combines the salient features of electrochemical machining (ECM) and mechanical machining (MM), offering enhanced precision, reduced tool wear, and the ability to fabricate intricate structures. While ECM facilitates material removal via electrochemical dissolution, MM refines structures through mechanical abrasion. This dual-process approach not only offers distinct advantages such as the ability to craft intricate microstructures and micro- and nano-features, but also the fabrication of advanced devices like MEMS and NEMS. Nevertheless, HEMM does pose challenges, including the need for specialized machinery and meticulous process parameter optimization. Electrochemical parameters such as electrolyte selection, voltage, and machining duration, and mechanical parameters including tool selection and feed rate play pivotal roles in achieving the desired outcomes. Through empirical, analytical, and numerical optimization methods, HEMM's performance can be fine-tuned to meet specific requirements. Its applications span various fields, from microfluidics and micro-optics to aerospace and biomedical devices, underscoring its transformative potential in contemporary manufacturing. This paper presents a holistic exploration of HEMM, aiming to consolidate its paramount role in future manufacturing paradigms.

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