NUMERICAL ANALYSIS OF THE FLUID FLOW WITHIN THE INTER-ELECTRODE GAP IN MICRO-ELECTRIC DISCHARGE MACHINING

By

Robert Samuel Reeve

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Approved by the
Examining Committee:

____
Johnson Samuel, Thesis Advisor

____
Onkar Sahni, Thesis Co-Advisor

____
Daniel Walczyk, Member

Rensselaer Polytechnic Institute
Troy, New York

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Abstract

Micro-electrical discharge machining (micro-EDM) is a non-conventional manufacturing process that is used to produce micro-scale parts/products that are otherwise difficult to be produced by more conventional tool to work-piece contact-based manufacturing techniques. The applications of this process span a wide range of industries including defense, aerospace, healthcare, automotive, and electronics industries with the collective applications representing a multi-billion dollar world-wide market. This process is an extension of the conventional EDM process, wherein an electric arc produced between a conductive 'tool' and work-piece combination is used to thermally erode the work-piece material, while both the tool and work-piece are submerged in a dielectric fluid. The characteristic tool sizes are in the 40µm to 300µm range with inter-electrode gaps (IEG's) in the 5-50µm range.

While the micro-EDM process appears to be fairly straightforward, it finds itself in competition with other emerging technologies such as laser micro-machining, partially due to the cost of the process. The prohibitive cost of the micro-EDM process is the result of relatively low material removal rates (MRR's), that are currently in the 0.6-6.0 mm^3/hr range, whereas material removal rates in the range of 10-15 mm^3/hr rate would be required for industrial viability. Research performed to-date attributes the relatively low material removal rates to the difficulty in the removal of debris material (formed during the erosion process) from the inter-electrode gap (the 'IEG'). The debris tends to linger in the active erosion zone, thereby hindering the process through re-welding of material or through the creation of electrical short-circuits. If methods can be developed

to more effectively remove debris material from the active erosion zone, then higher material removal rates can be achieved to make the process more economically viable.

The overarching objective of the research presented in this thesis, is to develop an understanding of the fluid flow-fields that exist in the IEG between the tool electrode and work-piece used in micro-EDM, in order that methods for effective debris removal could then be designed. To that end, this thesis focuses on the development of a computational fluid-dynamics model (CFD model) which is used to predict the flow-field experienced by the dielectric fluid in the inter-electrode gap as a function of tool geometry and operating conditions during a micro-drilling operation. AcuSim^{TM}, by Altair, is the software suite that has been employed for this work. Two separate geometries have been studied as part of this research. Geometry-A includes a cylindrical tool penetrating a cylindrical hole (i.e., a micro-drilling operation) where in addition to the rotation of the micro-tool, the work-piece is also ultrasonically vibrated at different frequencies and amplitudes. Geometry-B involves a tool that has a cross-sectional shape similar to the capital letter 'D', which is rotated while maintaining a stationary work-piece. For all simulation cases, the diameter of the work-piece hole is kept at 100 µm and the major diameter of the tool is kept at 80µm. The tool is simulated to be rotating at 1000 RPM while being submerged in the commercially-available "IonoPlus 3000ET" dielectric fluid manufactured by Oelheld GmbH.

Several interesting effects that are all directly applicable to the goal of increasing the debris-removal efficiency were found for both of the tool geometries. Zones of high-velocity, vena contracta type edge-effects, and asymmetric IEG flow-fields were found to occur in the cases using Geometry A. The influence exerted by these effects was seen to vary as a function of the amplitude and frequency of vibration. A transition from a primarily circumferential movement to a primarily-radial and axial movement was found to occur in the flow-fields of the Geometry-B ('D' tool) cases. While validating some of the experimental results seen in literature, the simulation results also provided several preliminary insights into the design of micro-EDM tool geometries that could achieve higher material removal rates. Although the findings in this thesis are a product of a simplified CFD model of the real micro-EDM process, they are the first step towards the building of more advanced CFD models that include realistic process conditions such as thermally-induced debris transport and electrical effects. Finally, the thesis concludes by identifying the future directions of this research.