Titel:

Towards economic simulations in pulse Electrochemical Machining

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Samenvatting:

Pulse Electrochemical Machining (PECM) is a manufacturing process which provides an economical and effective method for machining hard materials into complex shapes. One important drawback of ECM is the lack of quantitative simulation software to predict the tool shape and machining parameters necessary to produce a given work-piece profile. Simulation of the variable distributions during the PECM process provides information on system design and guidelines for practical use. Calculating e.g. temperature distributions in the system allows more accurate simulations, as well as the determination of the thermal limits of the system.

The pulses that are applied to the PECM system have to be described on a time scale that can be orders of magnitude smaller than the time scale on which the thermal effects evolve. If the full detail of the applied pulses has to be taken into account, the time accurate calculation of the temperature distribution in PECM can become a computationally very expensive procedure. In this dissertation the time scales in the system are identified. The knowledge of these time scales allows knowing in advance whether the variables will accumulate over multiple pulses during the process. It is also found that the way the system is modeled has a great impact on the temperature evolution in the thermal boundary layer. The presence of massive electrodes introduces extra time scales which may not be negligible.

In important regions of the system large and small time scales are encountered simultaneously. This troubles the approach of time averaging. When using plain time averaging to tackle the problem of the large time scales, the detail of the small time scales is lost, which significantly impedes accurate simulations. A new approach is used by combining averaged with pulsed calculations. The hybrid calculation and the Quasi Steady State ShortCut (QSSSC) are introduced. The hybrid calculation is a method, where at first averaged variable sources and afterwards pulsed sources are applied. With the QSSSC first an averaged Steady State (SS) is calculated using averaged sources, and afterwards pulses are applied. The latter allows a quick and cheap calculation of the Quasi Steady State (QSS). Using averaged calculations, the time steps are no longer dictated by the pulse characteristics and hence the large time scales can be handled. Combining the averaged calculations with pulses, the information of the smaller time scales is not lost. Computationally very cheap, yet satisfactory results can be obtained.

The hybrid calculation and the QSSSC are extensively studied on simplified analytical models. They are studied for heat transport in diffusive and convective systems, and for mass transport in diffusive systems. This theoretical study lays a sturdy foundation for the hybrid calculation and the QSSSC. The simplified models are too simple for the use in detailed calculations, but still very useful insights into the more general case are obtained. It is shown that the hybrid calculation and the QSSSC do not always deliver good results. However, using a technique of delaying the pulses in time, the results can become very satisfactory yet still extremely cheap. In detailed numerical calculations the concentrations will be

calculated simultaneously with the temperature due to mutual dependencies. The temperature in the diffusion case, the temperature in the convection case and the concentration calculation all have different requirements for optimal approximated calculations, and a compromise has to be found between them. This compromise proves to work out well. The results from the analytical study can be used as rules of thumb during detailed numerical calculations.

A two-dimensional model is presented that allows describing the high speed electrochemical machining of steel in NaNO solutions. Unlike existing models, local ion concentrations are calculated and used to evaluate local diffusion coefficients and electrolyte conductivity. Secondly, the presence of a super-saturated, honey-like layer on the anode surface is accounted for by introducing a water depletion factor. This factor describes the suppression of the oxygen evolution as the vast increase in ion concentrations reduces the amount of free water molecules at the anode. It is shown that this approach enables to reproduce experimental average efficiency curves over a broad range of electrolyte concentrations with just a limited set of adjustable parameters.

The approximative methods are applied on detailed numerically solved cases. Multiple geometries are simulated and analyzed and methods are compared. Very satisfactory, yet cheap results are obtained. The analytically obtained requirements for optimal approximated calculations perform very well for the numerically solved cases. The efficiency prediction model contains a changing polarization behaviour of the double layer as a function of the metal ion surface concentration. This formulation brings a strong non-linearity in the system. A strategy is introduced to integrate the non-linear model into the approximative methods. The hybrid method is extended to a method where the full system states during a whole pulse period can be calculated at any number of arbitrary moments in time. This is particularly interesting for integrating the calculations in a higher level time stepping algorithm, such as shape change.