Modeling of the Material/Electrolyte Interface and the Electrical Current Generated During the Pulse Electrochemical Machining of Grey Cast Iron

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Abstract

Pulse Electrochemical Machining (PECM) is an unconventional machining process combining pulsed current and mechanically oscillating cathode feed rate (Figure 1), being very suitable for high precision production in series manufacturing. The main advantage compared to conventional electrochemical processes is that the current pulse is only triggered when the efficiency is at its maximum, e.g. at the bottom dead center. This allows reaching smaller gaps (between 10 and 30 micrometers) compared to other electrochemical processes, which allows more accuracy [1]. Besides, during the pulse off-time the electrolyte in the interelectrode gap is refreshed by removal product free electrolyte, which guarantees constant electrochemical conditions for each following current pulse.

The electrical current and more specifically the electrical current density have a predominant and determinant influence on the processing results. The current density distribution under pulse electrochemical conditions on a metallography scale and the influence of the different machining parameters - voltage, pulse on-time, vibration frequency, feed rate and electrolyte pressure - on the dissolution characteristics - material removal rate and surface finish - have already been investigated for the machining of grey cast iron in previous works [2-5].

In this study COMSOL Multiphysics® was used to simulate the exact evolution of the current signal and its electrical characteristics - amplitude and phase - during the process depending on the set input parameters. Therefore, an equivalent circuit was developed beforehand using electrochemical impedance spectroscopy in order to determine the static and dynamic system interface properties due to adsorption, diffusion, relaxation or charge transfer (Figure 2). These elements are then implemented using the Electrical Circuit interface and coupled with the Electric Currents interface, in which the electrolyte properties are implemented depending on the experimental set-up geometry and the fluid circulation. The global impedance of the interface and the electrolyte can be derived as following (Figure 3), where Re is the resistance of the electrolyte, Cdl is the double layer capacitance at the anode, Rt is the resistance for charge transfer, Rl and L are responsible for relaxation and j is the imaginary unit. The electrolyte resistance is calculated from numerical simulation since it varies with the feed rate, the mechanical vibration frequency and the evolution of the interelectrode gap.

The first simulations and experimental results show a good accordance. Figure 4 represents the simulated and experimental current evolution at the anode during the pulse electrochemical machining of grey cast iron sample.

In conclusion, this study and the developed model will help predicting the in process electrical current evolution, respectively current density, and thus controlling the outputs by predefined input settings.

Reference

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Figures used in the abstract

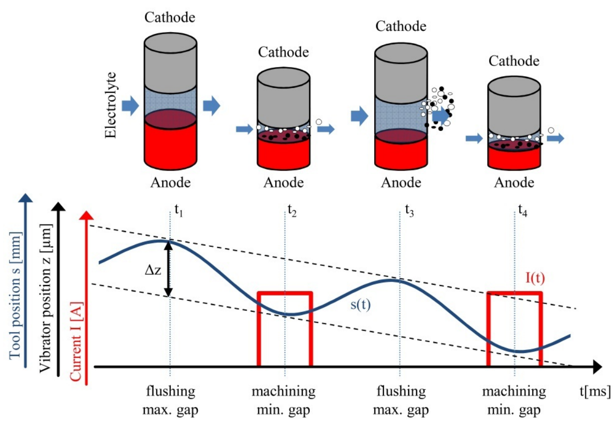

Figure 1: Principle of Pulse Electrochemical Machining

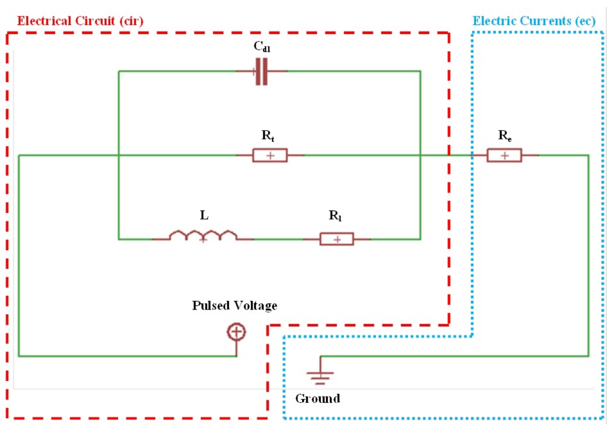

Figure 2: Equivalent circuit developed for the modeling and implemented in COMSOL Multiphysics 4.2a

$$Z_{global} = R_e + \frac{1}{\frac{1}{R_t} + \frac{1}{R_l + j \cdot \omega \cdot L} + j \cdot \omega \cdot C_{dl}}$$

Figure 3: Global circuit impedance

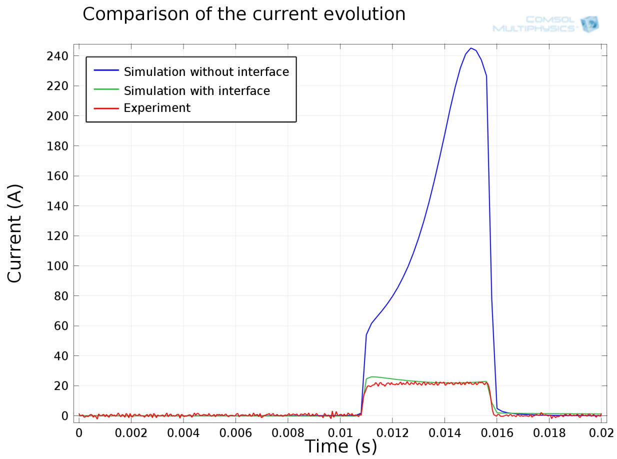

Figure 4: Comparison of the simulated and experimental current evolution