Analysis of repeatability for experimental characterization of lateral gap during Pulsed Electrochemical Machining

Richard Petermann[a,], Pascal Claußa, Gunnar Meichsnera, Frank Meyer[b], Steven Nickela, Matthias Hackert-Oschätzchena*

[a]*Chair of Manufacturing Technology with Focus Machining, Faculty of Mechanical Engineering, Otto von Guericke University Magdeburg, 39106 Magdeburg, Germany*

[b]*Laboratory of Production Measurement Technology and Sensor Integration, Faculty of Mechanical Engineering, Otto von Guericke University Magdeburg, 39106 Magdeburg, Germany*

*Corresponding author: richard.petermann@ovgu.de

DOI: 10.51382/978-3-96100-259-7-07

Abstract

Pulsed electrochemical machining is a manufacturing process, which is based on the principle of anodic metal dissolution. An ongoing challenge in the design process of removal devices is the estimation of the lateral working gap. An experimental approach was presented in a previous study. Here, the lateral gap was characterized for a corrosion and wear-resistant tool steel (1.4112). It was found that the lateral gap is influenced by the current density in the frontal working gap and the voltage. Furthermore, a change in the functional relations between these parameters coincided with a change in the current efficiency in the frontal gap. In this analysis, the repeatability of the experiments is investigated by applying a sample inspection. In addition, the application of a micrometer is compared with results obtained by applying CNC-measuring machines.

1 Introduction

Pulsed Electrochemical Machining (PECM) is an established manufacturing process based on the principle of anodic metal dissolution. Around the bottom dead center of the cathode oscillation, the material is removed by a direct current pulse. The removal products are flushed during the oscillation. [1,2]

The shape of the finished workpiece is largely determined by the shape of the cathode and the working gap between the anode and the cathode. The gap depends on, e.g. machining parameters, electrolyte conditions and material specific removal characteristics. As such, the prediction of the working gap for specific applications is often based on empirical methods. [2,3]

A systematic approach for the characterization of the lateral gap is described in [3]. It was found that the lateral gap can be described as a function of the current density in the frontal gap J_f and voltage U_q. This paper further investigates the repeatability of the results obtained.

2 Method and Experimental Setup

As mentioned, the working gap is not constant in PECM. The frontal working gap a_f (frontal gap) is generally defined as the gap between the cathode and anode parallel to the direction of the feed rate $\overrightarrow{v_f}$. During constant machining conditions, an equilibrium is eventually reached, which results in a constant frontal gap [2]. When machining with external or internal cathodes, the gap extends around the cathode. Here the local material removal gradually decreases due to the increase in distance from the cathode. The lateral gap a_s is defined as the perpendicular distance between the cathode and a surface of the anode parallel to the direction of the feed rate $\overrightarrow{v_f}$.

A schematic of an external cathode during the machining of a cylindrical anode with the definition of the frontal gap a_f and lateral gap a_s is shown in Figure 1 (left). [3]

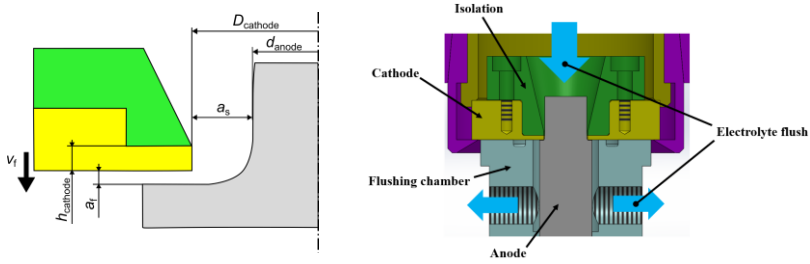

Figure 1: *Schematic of the dimensions of the applied cathode, resulting frontal gap a_f, anode and resulting lateral gap a_s [3] (left) and sectional representation of removal device with illustration of the flushing direction [3] (right)*

The dimensions of the cathode are described by the internal diameter $D_{cathode}$ and the height of the conductive cylindrical surface $h_{cathode}$. The lateral gap can be derived by measuring the diameter of the anode d_{anode} as described by equation (1) [3]:

$$a_s = \frac{D_{cathode} - d_{anode}}{2} \tag{1}$$

An estimation of the deviation of the lateral gap is given by equation (2) as shown by [3], where R_{anode} describes the roundness of the anode and $R_{cathode}$ describes the roundness of the cathode:

$$\Delta_s = \frac{R_{cathode} + R_{anode}}{2} \tag{2}$$

The experiments were carried out on a commercially available machine tool type PEM 800 S by PEMTec. The applied fixture is presented in Figure 1 (right). The dimensions of the cathode are specified in Table 1.

Table 1: *Specifications of the applied cathode [3]*

Parameter	***Symbol***	***Value***
Material		*1.4301 (X5CrNi18-10)*
Diameter	$D_{cathode}$	*10.0090 mm*
Roundness	$R_{cathode}$	*0.0086 mm*
Height	$h_{cathode}$	*0.923 mm*

3 Design of Experiments

The experiments were carried out applying the wear and corrosion resistant tool steel 1.4112 / X90CrMoV18 as anode. The constant and varied parameters are specified in [3]. Based on a material characterization [3,4] in accordance with DIN SPEC 91399 [5], the current density in the frontal gap J_f is derived based on the feed rate v_f. During the experiments, an electrolyte outlet pressure is created by a valve inside the PEM 800 S. A constant valve opening of 4 % was selected for all experiments, resulting in an outlet pressure p_{out} between 150 kPa and 240 kPa. The electrolyte enters the fixture at the lateral gap and exits through the frontal gap (see Figure 1 right) to ensure nearly constant electrolyte parameters in the upper lateral gap. [3]

In addition to the results of the 51 experiments presented in [3], 11 randomly selected parameter sets were repeated. The diameter of all samples was measured applying a CNC coordinate measuring machine PMM 866 by Leitz. The roundness was evaluated by applying a form measuring machine Roundscan 535 by Jenoptik (Hommelwerke). [3]

The diameter was additionally measured by applying a micrometer IP65 0-25 mm by Mitutoyo. Each measurement was repeated 5 times. The diameter d_{micro} represents the mean of these measurements. The deviation of the lateral gap $\Delta_{s,micro}$ was estimated as described by equation (3):

$$\Delta_{s,micro} = \frac{R_{cathode} + (\max(d_{micro}) - \min(d_{micro})}{2} + \Delta_{micro} \quad (3)$$

4 Results

4.1 Characterization of the lateral gap

Experiments were carried out to characterize the lateral gap. Initially, experiments based on a previous characterization [4] of the material removal were conducted. Additionally, 4 sets of experiments were conducted varying the voltage for a certain feed rate. The aim of these experiments was the investigation of the individual effect of the voltage on the lateral gap at different current densities in the frontal gap.

Figure 2 presents the lateral gap as a function of the voltage. The data is separated into two areas applying a threshold of J_f = 65 A/cm^2. This threshold coincides with a plateau of the current $\eta_{v\text{-}a}$ of around 85 % above 65 A/cm^2. [3]

As seen in Figure 2, the threshold divides the graph into two clear areas. For J_f > 65 A/cm^2, an increasing trend is obtained. In contrast, the data for J_f < 65 A/cm^2 shows no clear trend. [3]

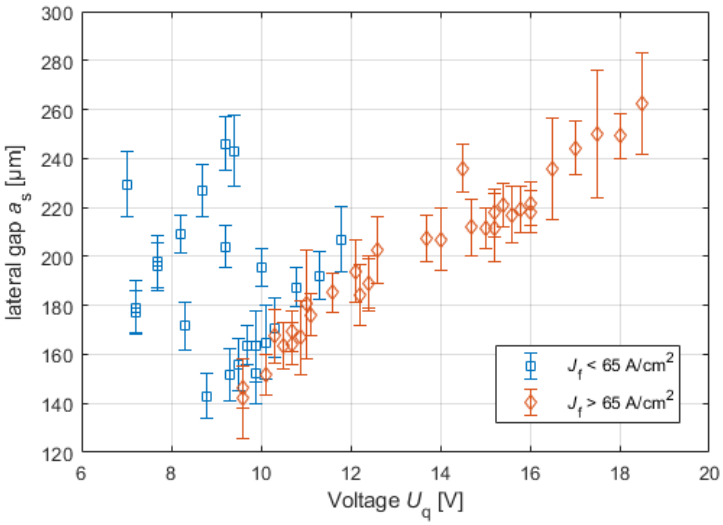

Figure 2: *Lateral gap a_s with estimated deviation as a function of the voltage U_q for two current density areas [3]*

The lateral gap seems to be dependent on the current efficiency in the frontal gap J_f and voltage U_q. The functional relation can be described by a function of the format presented in equation (4). [3]

$$a_s(J_f, U_q) = p_1 + p_2 \cdot J_f + p_3 \cdot U_q + p_4 \cdot J_f \cdot U_q \quad (4)$$

The resulting parameters are discussed in [3]. A degree of determination of 90 % is reached for J_f < 65 A/cm^2 and 96 % for J_f > 65 A/cm^2. Despite the different appearances of the trends of the lateral gap in Figure 2 the general effects of the voltage and current density are similar in both areas. An increase in voltage seems to have an increasing effect on the lateral gap. An increase in current density is seen to have a decreasing effect on the lateral gap. [3]

4.2 Analysis of Repeatability

The repeatability of the presented results was examined by repeating 11 of the 51 experiments. The experiments were selected by a random number generator. Current densities J_f in the range 49-110 A/cm^2 and voltages U_q in the range 7.2-18.5 V were investigated.

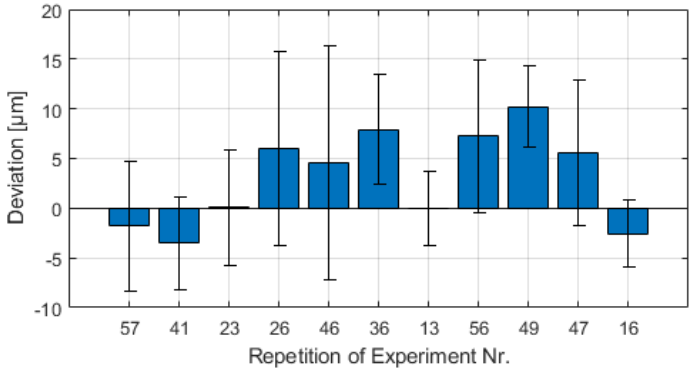

Figure 3: *Deviation of the lateral gap of the repetition experiments from the initial experiments (bars) with indication of the estimated deviation Δ_s of the repetition experiments*

Figure 3 displays the deviation between the lateral gap of the initial experiment and the repetition. The error bars represent the deviation Δ_s of the repeated experiments.

It is observed, that the deviations are in the range between -4 µm and +10 µm for the investigated parameter range. The deviation of the experiments itself Δ_s is mostly larger than the deviation between the experiments.

4.3 Application of a micrometer

The presented evaluation of the lateral gap, applying a CNC-measuring machine for all measurements, excels in a higher accuracy compared to other tools such as micrometers. The cost and time requirements attached to the presented process can although pose a significant barrier for industrial applications, such as preliminary experiments in fixture design. To reduce the time and financial effort, the application of a micrometer was investigated.

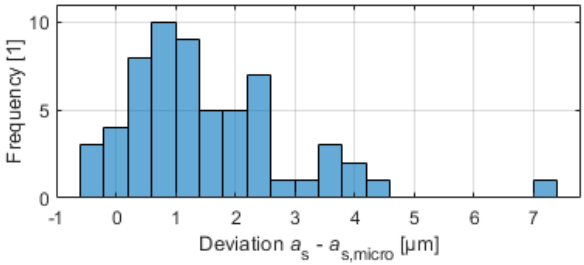

Figure 4: *Histogram of the deviation of the lateral gap a_s and the lateral gap obtained with a micrometer $a_{s,mico}$ for all experiments*

As mentioned, 5 measurements of each sample diameter were conducted directly after the execution of the experiment. The lateral gap was calculated based on the mean diameter of the sample. Figure 4 displays the statistical frequency of the deviation of the lateral gap. Two measurements were excluded due to a measurement error.

The mean deviation is calculated to +1.6 µm. The median deviation is slightly lower with +1.3 µm. Based on the assumption of a Gaussian distribution, an experimental standard deviation of 1.37 µm around the mean value is estimated. This results in a 4s interval of [-1.14 µm, 4.34 µm] with a width of 5.48 µm. The deviation of the lateral gap Δ_s averages around 11 µm, double the 4s interval, in comparison.

5 Conclusions

This paper highlighted an approach for the characterization of the lateral gap applying PECM. It is shown that the functional relation between the lateral gap and the current density in the frontal gap and voltage can be approximated utilizing the presented approach. The validity of the obtained data was investigated by repeating 20 % of the previous experiments. It was found that the repeatability of the lateral gap is comparatively to the deviation of the lateral gap itself. The comparison of measurements conducted with both a micrometer and a CNC measuring machine showed that the estimation of the lateral gap applying the micrometer leads to an underestimation of the lateral gap of around 1.6 µm. Therefore, the utilization of a micrometer can pose a cost-effective alternative for future industrial application of the presented method.

Acknowledgements

The machine tool PEM 800 S is funded by the German Research Foundation (DFG) with project number 467011871.

Literature

[1] *Schubert, A.; Meichsner, G.; Hackert-Oschätzchen, M.; Zinecker, M.; Edelmann, J.: Pulsed Electrochemical Machining of Powder Metallurgy Steels. In: B. Mollay et al: International Symposium on Electrochemical Machining Technology Confrence Proceedings, Wien, A, 2011, p. 68-75*

[2] *Klocke, F. et al: Fertigungsverfahren 3, Springer Verlag, Berlin-Heidelberg, 2007, p. 133-186*

[3] *Petermann, R.; Clauß, P.; Meichsner, G.; Meyer, F.; Hackert-Oschätzchen, M.: Experimental characterisation of lateral machining gap during Pulsed Electrochemical Machining for corrosion resistant tool steel. In: Procedia CIRP 137, 2025, https://doi.org/10.1016/j.procir.2025.06.009*

[4] *Petermann, R.; Clauß, P.; Meichsner, G.; Vogel, J.; Hackert-Oschätzchen, M.: Method for the Characterisation of the Material Removal in Modulated Pulsed Electrochemical Machining. In: Procedia CIRP 137, 2025, https://doi.org/10.1016/j.procir.2025.01.110*

[5] *Deutsches Institut für Normung e.V. (DIN): Methode zur Bestimmung von Prozesseingangsgrößen für das elektrochemische Präzisionsabtragen – Anforderungen, Kriterien, Festlegungen. Berlin: Beuth Verlag, 2018. DIN SPEC 91399:2018-02*