FACE MEASURING SYSTEMS FOR PARAMETER CONTROL OF ELECTRICAL DISCHARGE MACHINING

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Abstract
The on-line determination of the eroding face is very important for a corrected process control. The known capacitive and resistive methods of measurement fail because of the too high gauging accuracy required and the changeable tool-workpiece impedance. More precise methods are based on a model of removal and/or an evaluation of the voltage breakdown in the ignition stage.
A model for the face determination via removal should be presented. This model allows the check of the "middle current density" at varying effective eroding faces. Further problems concerning the need of measurement of the effective eroding face are discussed.

1. INTRODUCTION

The effective eroding face has a great importance for spark erosion machining. This effective face determines the current magnitude and the time for roughing and finishing.
A maximum thermal influencing should not be exceeded while roughing with an as high as possible removal rate. Under consideration of a stable process, the question must be answered whether abnormal discharges are permissible or not. The previous technologies are based on the determination of so-called limiting current densities for specific material combinations, which cause “slightly damaged” rim zone. This defined “middle current density” is not a real current density in the physical and/or electric sense because its definition according to Eq. (1).

$$\bar{j}_a = \frac{i_{gap}\,(i_e, t_e, \tau)}{A_{mf}\,(n_p, T_{rt}, \xi_p)} \tag{1}$$

The middle gap current i_{gap} is functionally dependent on the erosion current i_e, the discharge duration t_e and the duty factor τ. This relationship is valid for "ideal" rectangular pulses. The influence of the of the finite rise and fall times of pulses on the "middle gap current" must be considered in addition.
The "more difficult" rating is the "middle" effective work face A_{mf}. At small machining faces under 10 cm² the entire machining face (with $\xi = 1$) can be used as this value. However, at larger machining faces a part ξ_p may only be considered. This distribution factor includes the local limitation of discharges at an averaged time interval T_{rt}. At deeper sinking this value is also functionally dependent on the flushing conditions.
Why must the effective eroding face be measured? The problem of many applications consists in the variation the eroding face while sinking. A conical electrode is sinking the simplest example. Because of the continuous face change a continuous adaptation of the "middle working current" must occur. The face can be computed without problems for this simple example from the CAD data, therefore, this is an optimal test object for face measuring systems.

The methods of the face determination can be realised in very different ways. The present paper is concerned with machining small faces (< 2 cm²), because most problems occur here. The demands on the measuring systems are a face measurement carried out at a relatively short period (< 1 sec) and/or determination of the change of the face. In according to Eq. (1) the "middle current density" must be compared on-line with a model value and must be adapted to the optimal conditions. From the physical structure of the working gap, there are only three basic variants of the face determination,

- via the capacity of the eroding gap [2], [3], [1]
- via the gap impedance [4]
- via the technological removal rate parameters [5].

2. COMPARISON OF DIFFERENT MEASURING METHODS

2.1. Measuring the Gap Capacity

This group of procedures is based on utilisation of a test pulse which is sent out at the break time between the eroding pulses or at a time of the process interrupt. The condition for this test pulse is that no discharge may occur. The measured gap capacity C_{mess} consists of the capacitive parts of the frontal gap C_{fg}, of the lateral gap C_{lg} and of the machine intern part C_{in}. As a result, the computed face is larger than

the searched projected, effective face, what causes the determination of a too small “middle current density”.

$$C_{mess} = C_{fg} + C_{lg} + C_{in} \tag{2}$$

If the capacity C_{in} can be measured, it may be used as correction size in Eq. (2). Now the relationship between the face conditional capacity change and the total capacity must be found out. Practical measurements at industrial sinking-plants showed, that the plant capacity (10... 20 nF) is much larger as the gap capacity (100 ... 200 pF). Therefore, measuring systems with a very high gauging accuracy must be used, because the relevant capacity changes are only of 10 ... 20% gap capacity.

$$\frac{C_{mess} - C_{in}}{\varepsilon_0 \cdot \varepsilon_r} = \frac{A_{fg}}{a_{fg}} + \frac{A_{lg}}{a_{lg}} \tag{3}$$

The lateral working gap falsifies the searched projected face (Fig. 1), because it is only involved in a conditional manner in the removal process. An evaluation of the rise rate of pulse gives more precise information about changes of the eroding face if the gap conditions remain constant. However, the separation of the relevant frontal capacity from the measured entire capacity remains problematic.

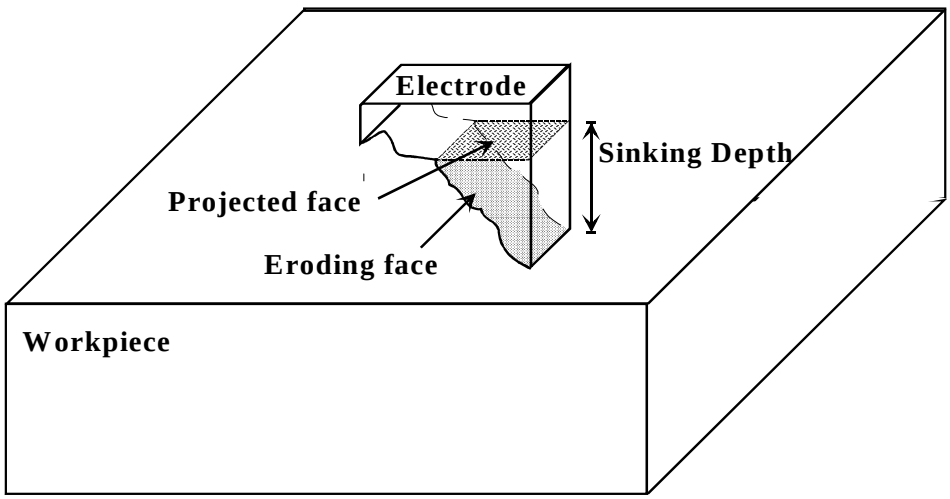


Fig. 1 Faces of the EDM

2.2. Measuring the Gap Impedance

The method of measurement via determination of the gap resistance has the same problems as the capacitive method. Partly the measurement errors are even bigger because the partial conductivity in the working gap changes in some orders of magnitude. The measured impedances are also falsified by the pollution (removal particle) and local overheating of the dielectric. The gap influence a_{fg} is the same, as the case of capacity measurement.

$$\mathbf{A} = \frac{\mathbf{I_{mes} \cdot a_{fg} \cdot \rho_{df}}}{\mathbf{U_{mes}}} \qquad \textbf{(4)}$$

Eq. (4) shows that the specific electrical resistance of the dielectric has a linear influence. The hydrocarbons are unsuitable for this analysis because a very high measuring voltage is necessary in order to achieve an evaluable measuring current. For water based dielectrics, analyses of larger work areas can be carried out.
The separation of face influence from the other process influence parameters is very critical especially at water based dielectrics, since strong local modifications of conductivity through removal particle and discharge channels of sparks occur.
The decoupling of these factors by the measurement equipment is hardly possible so that these methods can not be applied especially for small faces and face changes.

2.3. Measuring the Technological Parameter

A further possibility of the face determination is based on use of technological parameters, of model parameters with continuous removal, and ist also possible by predeterminablee wear and by graphical data of the CNC control.
Assumptions for this procedure are:

- high repeatability of the pulse parameters;
- very precise model of removal for workpiece and tool;
- sufficing period for calculation (millisecond) of the current projected face.

Investigations of Dehmer [8] and at the University Magdeburg are starting point of theoretical analyses. [5], [6]. The removal volume of one pulse is calculated according to Eq. (5).

$$\mathbf{m_m^I} = \begin{cases} \mathbf{a \cdot t_e \cdot i_e^n + b \cdot t_e^2 \cdot i_e^m} & \mathbf{t_e \le t_{e\,lim}} \\ \mathbf{const. = f(i_e)} & \mathbf{t_e \ge t_{e\,lim}} \end{cases} \qquad \mathbf{(5)}$$

The removal at the workpiece and the tool distinguish itself only by the coefficients a, b, n and m. Those can be determined very fast during ideal rectangular pulses for a defaulted material combination. Eq. structure (5) changes if materials as graphite (sublimated) are used. Then the function subdivides itself into several sections which are featured by the following facts.

- Up to sublimation temperature (solid), a high model accuracy and a small wear (tool);
- Non-reversible tool removal in terms of the sublimation temperature (gaseous);
- Transition region is critical in model formulation.

The repeatability of the pulse parameters can be implemented by a process energy supply on the basis of a current source with very constant current amplitudes. Deviations in the rectangular pulse process must be added by further correction factors (via energetic relationship) into the model. This correction can be avoided by hardware solutions of the energy supply [7].

The time for the determination of the current eroding face is in the area of milliseconds, i.e. problems only occur during the determination of very fast face changes.

The procedure only depends on the correct determination of the effective electrical discharge. In the case of a stable process, all effective discharges are spark discharges and Eq. (5) is valid without limitation. In the transition region between stable and unstable process “abnormal” discharges arises. In our investigation, it was found out that the model approaches must not to be changed, if arc discharges are faded out.

In **Fig. 2**, it is recognisable that a small diameter deviation of the electrode at small faces can cause great distribution changes, if arc discharges are not faded out.

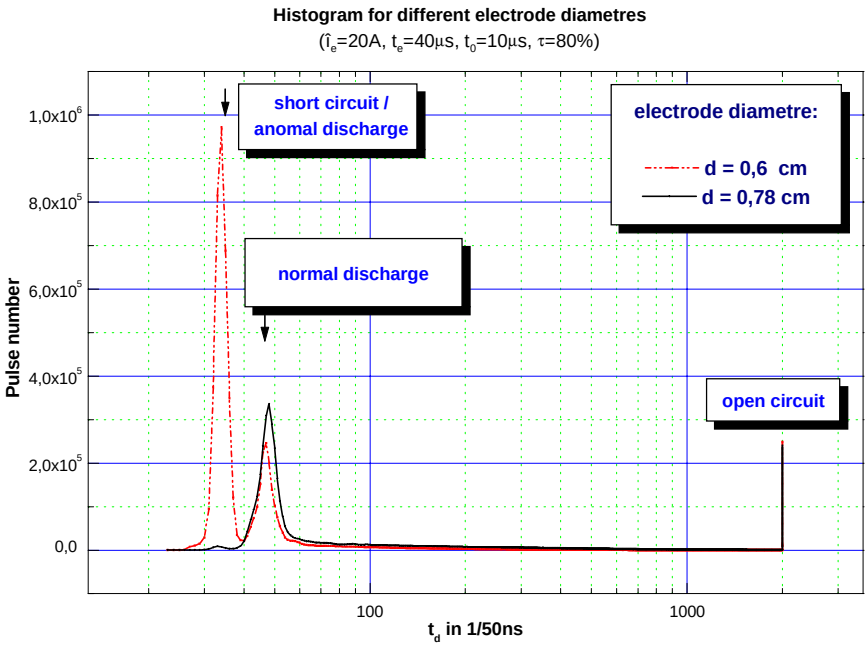


Fig. 2 Pulse histogram for critical current density

3. FACE MEASURING SYSTEM AN INFLUENCE OF PARAMETERS

The face measuring system works in accordance with the block schematic diagram in Fig. 3. Because the models are stored in PLD's they can be modified or complemented fast. The data editing and parameter changes occur by means of µ-processor.

The investigations showed that a stable process can not be achieved if current density (Eq. (1)) increases over a critical value $J_{critical}$. Achieving the process stability again, the current density had to be lowered clearly below the critical value from the former state. It follows from this that the critical current density has a hysteresis and an upper (upwards) and a lower (downwards) critically value is to be defined. The cause of the current density change also leads to different critical values. With an enlargement of the current amplitude, the current density becomes larger per discharge, whereas in the case of bigger duty cycles and longer pulse duration the local effective time is increased. The enlargement of the face can cause a better distribution of discharges, in this way, a reduction of local current density follows.

The pulse frequency on a surface segment is increased by the reduction of the eroding face, therefore, an enlargement of local current density occurs.

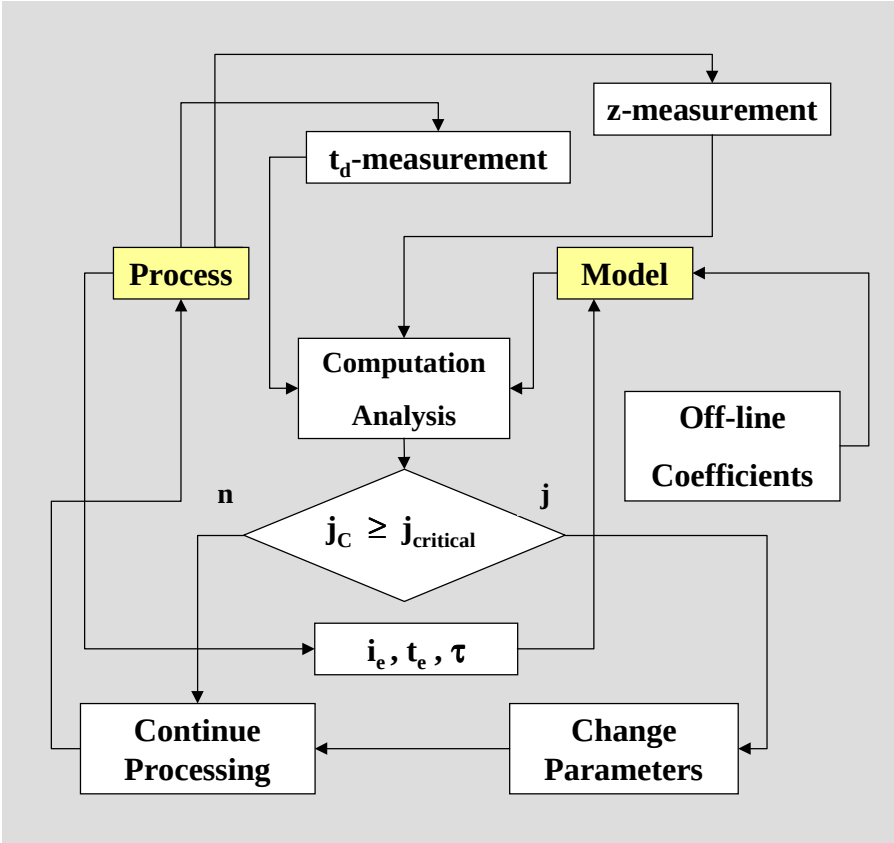
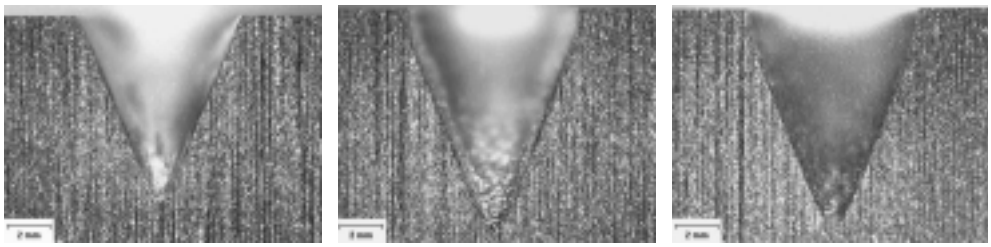


Fig. 3 Block schematic diagram

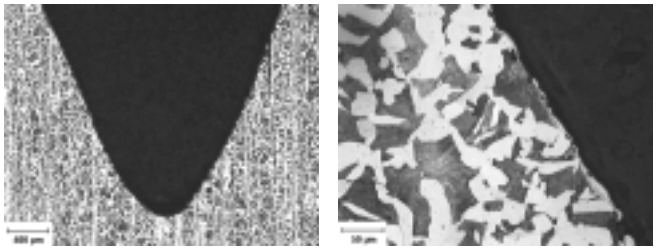
From the basis investigations for spark erosion can be concluded, that the change of time parameters has a higher influence to critical current density than an amplitude variation. While machining of big faces face changes are uncritical because an almost constant effective area results by the averaging time. While machining of small faces under 2 cm², the influence of a face change increases, therefore, the averaging times must be adapted in this case.
At a practical example could be verified, that eroding with face adapted parameters can reduce the machining time essentially. In this case, a reduced wear was observed additionally.



Finishing (reduced sinking depth)	Roughing without finishing	Adapted without finishing

Fig. 4 Cone sinking (EDM) with different strategies

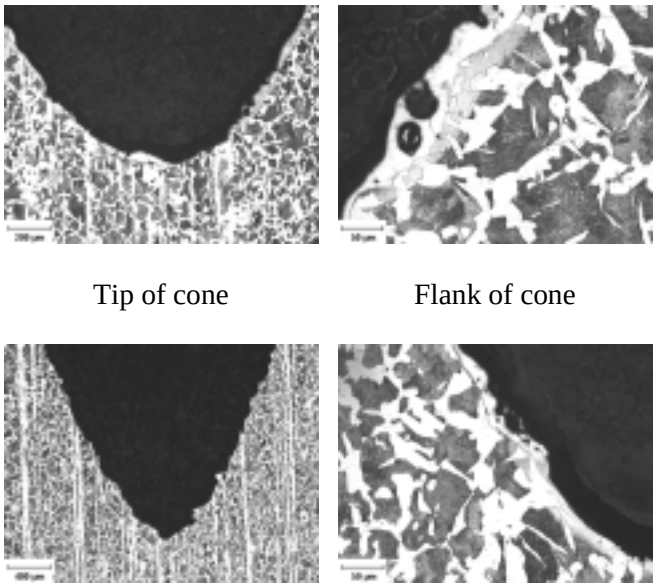
For the sinking of a cone of 10 mm with finishing technology (5 Amp; 12 µs; 6.5 µs) at a serial machine an machining time of 320 minutes was achieved. The length-wear was ~ 0.5 mm without further finishing (~5%)
In the second case the same machining experiment (12 mm) with maximal permissible current density for the largest electrode face (16 Amp.; 200 µs; 25 µs) was carried out. Machining including a finishing lasts only 50 minutes but the length-wear was doubled (~10%)
In the third experiment (12 mm), a parameter adaptation to be determined face was carried out after each 0.25 mm of feed distance, where the parameter variability was limited by serial machine. Including a finishing an machining time of 80 minutes and a reduction of length-wear to ~ 0.25 mm (~2.5 %) was achieved.
Fig. 4 shows the result of ED machining by use of parameters for finishing, roughing and adapted parameters. The main problem is the extreme apex rounding what is caused by roughing with middle current density larger as $J_{critical}$.



ED Finishing
a) tip of cone (apex) (400 µm)
b) rim zone structure (50 µm)

Fig. 5 ED Cone-Finishing

In Fig. 5, the desired result of the ED Cone sinking is shown. The significant “White Layer” can be eliminated with a varied finishing range. The results of roughing and the machining with adapted generator parameters is shown in Fig. 6.



ED-Roughing with maximum of current density (200 µm)

Tip of cone Flank of cone

Adapted face conditions
Without finishing (10 µm)

Fig. 6 ED Cone-Sinking with roughing (above) and adapted conditions (below)

4. CONCLUSION

The essential advantages of machining with adapted parameters are the higher process stability and resulting from this the significant lowering the machining time. The thermal affected surface becomes smaller. In some cases a reduction of wear is possible. The precise knowledge over the currently effective eroding face is important for a modern process analysis system, because then the current density for roughing can be increased by modification of generator parameters up to the middle limiting current density. The accuracy of the face measurement depends on the quality of the process energy supply, the models for the removal behaviour and the quality of the feed control. Not “ideal” pulses from the generator,e.g., require an enlargement of the number of variables in the model approaches.

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