Demands on process and process energy sources for the electro-erosive and electrochemical micro machining

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ABSTRACT: This article will demonstrate which demands are required from process energy sources (PES), if the non-conventional machining procedures EDM (Electrical Discharge Machining) and ECM (Electrochemical Machining) are efficiently used for the micro machining. Due to the very low working gap, the process conditions are considerably changed compared to the previous machining conditions. The well known PES-concepts can no longer be treated without paying attention to the supply parameter (feeder parameters) and the gap parameter. A very efficient machining procedure is the µ-PECM, which uses the charge reversal of double layers.

Key words: EDM, ECM, process energy source, PECM, µ-PECM

1 INTRODUCTION

The article shows that the quality of micro machining using EDM, ECM and their combined procedure depends on design and concept of the energy source. The rather different removal mechanisms are primarily determined by the characteristics of the working medium [1,2] (s.

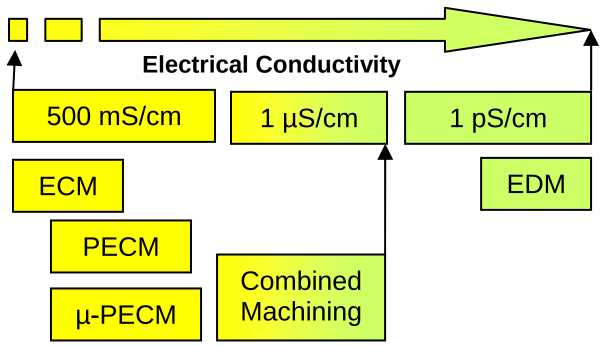

fig.1).

Fig.1. Influence of electrical conductivity of the micromachining on non-conventional processing

During the micro machining additional problems arise because the distance of the electrodes is smaller than 10 µm and might become smaller than 1 µm for the precision machining.

A big advantage of non-conventional machining procedures is the force-free machining of the work piece due to the fact that it works without contact, which is especially relevant for filigree structures.

The development of the process energy sources (PES) had been publicized only to a small extent so far. The reasons for that can be seen in the development of energy sources being mainly pursued by machine producers, while only a few universities in Europe carry out an own further development of process energy sources [3,4].

2 DEFINITION OF THE PROBLEMS

In the following the problems for the micro machining alone shall be presented. The boundary conditions are defined by the applications of the industry.

Firstly, the gap distance in the working area shall be smaller than 10 µm and the machining surfaces smaller than 100 mm². The basic procedures take place in a liquid medium, while selected applications might also be treated as a dry process (gas as medium).

Secondly, contamination and regeneration period determine the formation of the current and voltage pulses of the PES.
Thirdly, the machining procedures require different current-voltage-characteristics of the PES and a very exactly dosed energy per pulse. When applying the micro machining the pulse energy must not generate a thermally effected surface. Likewise, the removed volume must be controlled by a respective feed control in a way that at the moment of the removal the gap distance does not exceed the boundary value preset by the machining accuracy.

2.1 Gap contamination

The gap contamination is divided into three crucial types (see fig. 2)
The first **Type S** is the solid removal parts which can be found in the working gap directly after the removal process. In case of energetically optimal conditions, the removal parts are considerably smaller than the working gap, i.e. problems can only occur because of “washed-out” structures (e.g. grains size).
The rinsing conditions within the working gap are improved by additional oscillation, rotation and/or vibration of the tool electrode, so that the breaking period of the pulse sequence can be shortened.

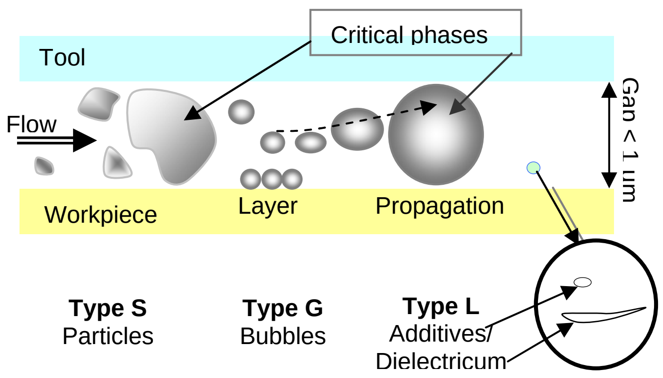

Fig.2. Gap contamination for EDMM

The second **Type G** is the gaseous removal parts which can arise because of the discharge channel (EDM) or the chemical surface reactions (ECM).
When using EDM the dimensions of the gas bubbles can be determined by the pulse energy and the pulse duration. However, it is still unclear how characteristics like surface tension, boiling enthalpy, binding energies and heat conductance effect on the expansion of the discharge channel (plasma channel plus gas bubble) in very small working gaps [5]. The local effect of the ED-removal also causes gas bubbles which, however, lead to very different breakthrough conditions in the working gap due to their fast expansion.
When using ECM the gas formation takes place over the whole surface of the working gap, while on account of the pulsed ECM (PECM) improved conditions are generated for the “degassing” of the gap. Another influential aspect is the passivation during the ECM. If the passivation is local, then the gas formation will also be localized, deteriorating the removal process.
Gas phases can build up passivating layers in this respect, which are the basis for combined procedures.

The third **Type L** is the liquid products of the pyrolysis, taking place mainly in the EDM (plasma channel). These corrosion products in the liquid phase are very low in percentage and do not pose many problems (nm-dimensions).
Based on investigations of ignition procedures for EDM in working media with additives, it can be assumed that the short-time presence of liquid pyrolysis products have no influence on the removal process [6].

2.2 Process energy source (EDM)

In the following some important problems concerning the conception of process energy sources shall be named:

- The reduction of the pulse energy for the EDM is limited, as for current amplitudes smaller than 800 mA (depending on the electrode material and the dielectric) there is no more spark discharge. The glow discharges lead to a quick evaporation of the working gap medium and a cleansing of the workpiece surface.
- The reduction of the pulse duration is limited by the electrical components and the required supply line (Feeder). Current amplitudes of approx. 1 A pulse durations in the range of nanoseconds can be gained, after that higher pulse sequence frequencies are no longer possible. Circuit-based solutions are by 5 A, 80 ns and 2 MHz at the moment [4].
- There exists a large discrepancy in the demand for a minimal working gap (< 10 µm) and process stability. A high process stability can only be achieved, if higher ignition voltages (re-

ignition) are applied.

- In the field of micro machining the process control becomes more difficult, as the wanted signals do not deviate largely in their amplitudes from the unwanted signals. Due to the large current and voltage rises, additional EMV-problems occur. The unwanted signals injected from outside (e.g. working gap) have to be separated from the "real" process signal. However, the short pulse durations do not allow a long signal processing anyhow.

2.3 Process energy source (ECM)

For the ECM basically three machining variations can be differentiated. The original ECM is a procedure with DC-voltage source (**DC-ECM**), being mainly used for the machining of large areas. With the pulsed ECM (**PECM**) clearly better machining conditions are achieved, e.g.

- for the heating of the electrolyte,
- for the rinsing of the working gap,
- for the use of higher current densities

In the micro machining pulse durations smaller than 50 µs to approx. 1 µs can be gained, leading to an improvement of the surface quality and the machining precision. In the previous variations an external PES had always been used. The removal rate was exclusively determined by the gained current density, with the pulsing of the current being determined by the achievable current rise speed.
The third variation - **µ-PECM -** uses the reloading of the electrochemical double layers for the removal [7]. Because of that, very small structures (< micrometers) with a very high machining precision can be processed. The momentary development potential of this procedure is based on the electrolytes and the driving energy sources for surfaces larger than 100 x 100 µm². This variation with internal PES also corresponds to the procedure of electrolytic polishing.

2.4 Combined Machining

The procedure combinations of EDM and ECM respectively use the advantage arising from the gap conditions. The PES has to be designed for both procedures. Using micro machining, this combined machining had been really efficient so far for the hole sinking [8].

3 SOLUTIONS FOR MICRO MACHINING

3.1 Micro Electrical Discharge Machining (µEDM)

The concepts for PESs of the µEDM are static impulse current supplies, ranging from pulse durations of 1 µs to controlled relaxation generators with pulse durations < 100 ns.
Fig. 3 shows the u-i-characteristic of a voltage-controlled current supply [8]. The advantage of this supply is on the one hand the adjustability of the working current and, on the other hand, the parallel control of the cut-off voltage of the supply. Due to the electrical conductivity of the working medium, the working current is divided onto ED and EC parts.
The advantage of the relaxation generators is their gap-based adjustment of charge and discharge of the storing element (R, L, C, diode, transistor). Consequently, the pulse energy only depends on storing elements.

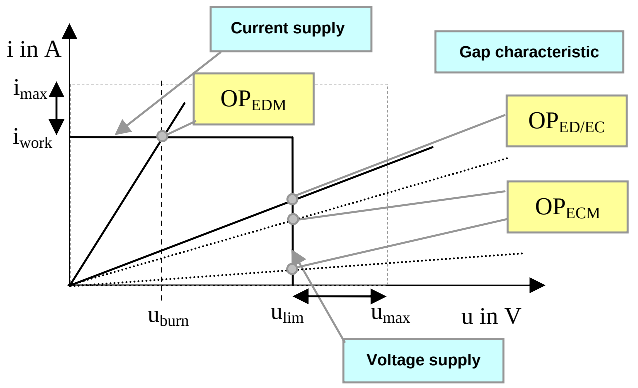

Fig.3. Current-Voltage-Characteristic of the voltage-controlled current supply

Another way for minimizing the local energy in the plasma bases is to use base point splitting and base point movement. The latter is less applicable in case of very short pulse durations (<< 1 µs) and gap distances of << 5µm. Yet, the splitting of the plasma base point provides a chance to let effect lower currents in the plasma channels per discharge despite minimal current boundary values. The basic concept lies in the control of the process energy source, the quick process phase recording and the refeed to the pulse forming. The basis of this PES is the pre-ignition phase in the working gap, where a multitude of streamers arise that is in the range of nanoseconds in the „base points". Fig. 4 shows how by way of a short-time effect of the streamers a minimization of the removal-effective pulse energy might occur.

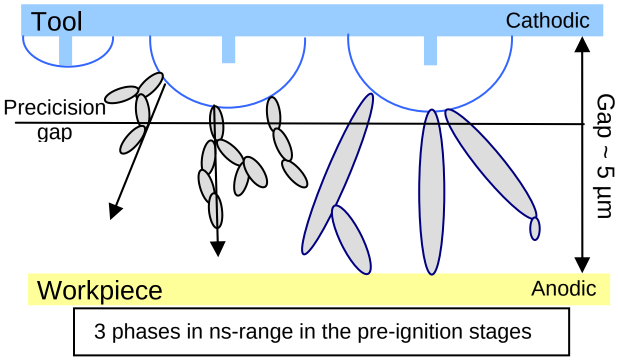

Fig. 4. Streamer propagation in the micro gap

This effect has already been used for the EDM in gases [8,9], yet here the cleansing of the working gap for gap distances << 5 µm is a problem, especially in case of complex structures.

A solution could also be gained by way of the grouping of needle pulses (needle pulses), which steadily cause a short-time breakdown and re-ignition of the discharge channel. The grouping of these pulses is necessary to guarantee the required rinsing within the working gap.

3.2 Pulsed Electrochemical Micromachining (PECMM)

PECM investigations are a very popular research field among the institutes at the moment [10]. In contrast to the EDM, it has to be very precisely analyzed which current densities and electrolytes might be used to generate efficient removal rates and high surface qualities. Passivating electrolytes require current densities which are in the trans-passivating parameter range for maximum pulse durations. The previous concentration on aqueous NaCl or $NaNO_3$ electrolytes can not be maintained.

The problems regarding the electrical equipment change from PES to a fast process data recording and the control of process instabilities like short circuits.

As for the micro machining of surfaces smaller than 100 µm², µ-PECM is the most appropriate machining variation. The voltage supply driving the internal PES has to be adjusted to the feeding (Feeder) and gap conditions.

4 CONCLUSIONS

Without the further development of the PES of EDM and ECM there is no chance for the machining procedures to efficiently improve the micro machining. A very good solution for the micro machining is the µ-PECM.

The research in the field of electrical equipment can not be realized without including supply lines, electrode arrangements, characteristics of the working media and thermal stresses.

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