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On machine measurements of electrode wear in micro EDM milling

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Abstract. The electrode wear in micro electrical discharge milling (micro EDM milling) is one of the main problems to be solved in order to improve machining accuracy. Most common, the electrode wear is measured on machine by touching the reference point with the tip of the electrode (Touch method) after machining a certain number of layers. The reduction of the electrode length due to the wear (linear wear) is used to modify the electrode trajectory. A laser scan micrometer (LSM) is implemented on the machine mostly to acquire electrode profiles after dressing of the electrode is applied. It is also an alternative solution to measure the linear and volumetric wear, which in principle should be more accurate compared to the measurements performed by The Touch method. In this paper, the performance of the two systems, namely Touch and LSM, were compared. The experimental results show that the accuracy of the electrode length measurement by the Touch method is enough accurate for the linear wear estimation, but the volumetric wear should be measured by LSM system.

Introduction

Micro-electrical discharge milling (micro EDM milling) is a thermal (or energy-assisted) process for contactless material removal of electrically conductive materials. In micro EDM milling, the machining of conductive materials is performed by a sequence of electrical discharges occurring in an electrically insulated gap between a tool electrode and a workpiece. During the discharge pluses, a high-temperature plasma channel is formed in the gap, causing local melting and evaporation of workpiece and electrode material. The capabilities and potentials of micro-EDM processes are thoroughly discussed in [1] .

In micro EDM milling, micro electrodes are cylindrical rods with diameters down to 10 µm, which are driven along defined paths while rotating, in a way similar to conventional 3 and 5 axis milling. In this configuration the material is removed layer by layer, with layer thickness ranging from a 0.1 µm to few microns, depending on the diameter of the electrode and on the discharge energy. Currently, micro EDM milling is mostly used for the production of micro cavities with high aspect ratio and tools employed in mass or batch production of micro components, as for instance micro moulds for micro injection moulding.

However, it is necessary to integrate CAD/CAM systems with micro EDM milling to generate tool paths when simple-shaped tools are used to machine three-dimensional micro-parts [2]. During the machining, the linear wear of the electrode (=the reduction of the electrode length) has to be compensated by movement of the electrode in z axis. Many types of tool electrode wear compensation methods have been studied and applied successfully in research laboratories [3], but their introduction into an industrial manufacturing environment is not straightforward [4]. After machining of one or several layers, the linear wear has to be measured to re-estimate the compensation factor. Hopefully, the compensation factor converges to a certain value after a few measurements, but the linear wear is checked throughout the machining. It can only be achieved by implementation of the on machine measurement (OMM) system.

In this paper, the repeatability of the two methods used for on machine linear wear measurement is addressed. The most often used method is a linear wear measurement by touching the reference point by the tip of the electrode (Touch method). The voltage drop between the reference point and the electrode indicates the contact between the two points. When the voltage drop occurs, the movement in z direction is stopped and the z coordinate is stored in the memory of the controller. After one or a few layers of machining the z coordinate is checked again by the same procedure. The difference in z values before and after machining a certain number of layers equals to the linear wear. The drawback of such method is that the electrical contact produces a small amount of erosion, which would cause an error in the measurements of the actual linear wear value [5].

The second method under the scope of this paper is similar to the Touch method. Here, the z coordinate is not measured by the voltage drop, but by interrupting the laser beam with the electrode tip when moving in z direction in Laser Scan Micrometer (LSM). The movement is stopped when the beam is interrupted and the z value is stored in the file. LSM system enables acquisition of the electrode profile, thus the corner wear and volumetric wear can be accurately measured.

At last, the LSM system was used to acquire the volumetric wear and to compare the results by the simple calculation of the volumetric wear from the linear wear. Further on, the corner wear of the electrode was examined for various machining parameters.

2. Methodology to compare the two OMM methods

Assessment of the OMMs in this paper is based on repeatability of the measurements. Repeatability is only one of the contributions to the uncertainty of the measurements, but it is sufficient to compare the two methods, namely the Touch and LSM method. Both methods were applied to measure the electrode linear and volumetric wear.

2.1 Linear wear

The electrode length was measured before and after machining by the Touch method and LSM system. The electrode length (either before or after machining) was performed five times and the mean value of the electrode length (x) and standard deviation (σ) for each of the five experiments were calculated.

The linear wear (Δl) was calculated by subtraction of the average value of the electrode length after machining ($\bar{x}_{\text{after}}$) from the average value before machining ($\bar{x}_{\text{before}}$) (Eq. 1).

$$\Delta l = \bar{x}_{before} - \bar{x}_{after} \tag{1}$$

The standard deviation of the linear wear was calculated according to Eq. 2 assuming the length measurements before and after machining are normally distributed.

$$\sigma = \sqrt{\sigma_{before}^{\;2} + \sigma_{after}^{\;2}} \tag{2}$$

The same machining operation was performed five times and the linear wear was measured for each operation.

2.2 Volumetric wear

The volumetric wear can be estimated from the linear wear (Δl) of the electrode and the electrode diameter (d). The linear wear was measured by the OMMs. The diameter of the electrode was measured by LSM system and it was used as a constant value in the volume calculations of both methods. The volumetric wear is calculated by Eq. (3).

$$V = \frac{\pi \cdot d^2}{4} \cdot \Delta l \tag{3}$$

LSM system enables not only to measure the electrode length, but also to acquire the electrode profile without removing the electrode from the clamping head. To have a reference for comparison of methods for linear and volumetric wear estimation, the electrode profiles were acquired before and after machining. The volumetric wear in this case was calculated according to Eq. 4

$$V = \int_a^b \pi \cdot f^2(x) \cdot dx \ , \tag{3}$$

where *f(x)* describes the electrode profile. The calculations were performed numerically based on the points of the electrode profile starting from point *a* and finishing in point *b*.

3. Experimental setup

The experiments were performed on a Sarix SX-200 high precision micro-erosion machine. The machine is equipped with a wire dressed unit and with a Mitutoyo special type LSM-500s with declared repeatability of 0.03 µm. The resolution of measured values was 0.1 µm.

A simple blind hole with a diameter of 500 µm and 100 µm deep was picked out as the target feature to be performed in micro EDM milling configuration on a martensitic stainless steel AISI 420 modified (STAVAX ESR) workpiece. The holes were machined by means of circular interpolations with radius 100 µm. No wear compensation was used to adjust the electrode path accordingly to the gap and the wear. The machining direction has been changed alternatively between clockwise and counter-clockwise for each layer to minimize the residual material on the bottom of the hole that can occur due to the tool wear. The electrode has been cut flat ground using the wire dress unit before each test run. In order to perform the same procedure in all experiments, a G-Code program was compiled with all the instructions needed to measure the electrode by Touch method and by LSM system, to machine the cavities, to cut the electrode and to position it above the starting point of the following test. The machining parameters are given in Table 1.

Table 1
Micro-EDM parameters settings

Energy [index]	Polarity [-]	Width [index]	Frequency [index]	Current [A]	Voltage [V]	Gain [index]	Gap [index]	Layer depth [µm]
15	-	6	100	70	80	75	65	0.5
105	-	6	100	65	100	75	90	0.9
206	-	5	130	50	130	80	100	2.5
250	-	5	130	50	130	50	97	2
300	-	4.6	130	50	130	70	100	2.5
350	-	4.6	130	50	130	50	100	2.5

A cylindrical rod made of tungsten carbide with a nominal diameter of 300 µm was used as a tool electrode. The diameter of the electrode used in experiments has been determined to be 296 µm with a tolerance of ±1 µm. Hydrocarbon oil (HEDMA 111) with a kinematic viscosity of 2.4 cSt at room temperature was used as dielectric.

3. Results and discussion

3.1. Linear wear

The results for energy level E350 are gathered in Table 2. Other energy levels gave similar results, thus they are not presented here. The measurement of the length of the electrode by LSM always gave the same results in five repetitive measurements. Since the file resolution of the measurements is 0.1 µm, the repeatability of LSM system is less than 0.05 µm. This result is in a agreement with the declared repeatability of LSM system provided by the manufacturer: 0.03 µm. In the table, the repeatability provided by manufacturer is given. On the other hand, there is no declared repeatability for the Touch method.

Table 2
Electrode length measurements for energy level E350

Before machining		After machining		Length		LSM	
x [µm]	σ [µm]	x [µm]	σ [µm]	x [µm]	σ [µm]	x [µm]	σ *[µm]
2999.4	0.4	2929.8	0.1	69.7	0.4	69.6	0.03
2999.3	0.0	2931.8	0.7	67.6	0.7	67.5	0.03
3008.5	2.0	2929.5	0.1	79.0	2.0	79.0	0.03
2996.6	0.1	2929.4	0.2	67.2	0.2	67.2	0.03
2997.7	0.1	2930.5	0.1	67.1	0.2	67.1	0.03

* Repeatability of LSM system defined by manufacturer

The variation of the linear wear measured by Touch is not equal for all experiments, since the standard deviation of the five measurements performed by touching the reference point is not equal. It ranges from 0.1 to 2.0 µm. On the other hand, the biggest difference between the average value of the linear wear measured by the Touch and by LSM is 0.1 µm. The mean value of the five repetitive measurements by touching the reference point gives a good estimation of the electrode length and consequently also the linear wear. The use of an expensive LSM system does not significantly improve on machine linear wear measurements if the electrode length is measured five times and the average value is considered as the electrode length.

3.2 Volumetric wear

The results of measurements of volumetric wear are given in Fig. 1. One can observe that the main source of variation is the machining process itself and the influence of the measuring technique does not play an important role. Volumetric wear calculated through the LSM measurements of the electrode profiles defines higher tool wear rate for all energy levels (Fig. 1, LSM - profile column). The acquisition of the electrode profiles takes into account also the rounding of the electrode edges, which is not considered in the calculation of the volume based on the linear wear (Fig. 1, LSM and Touch columns).

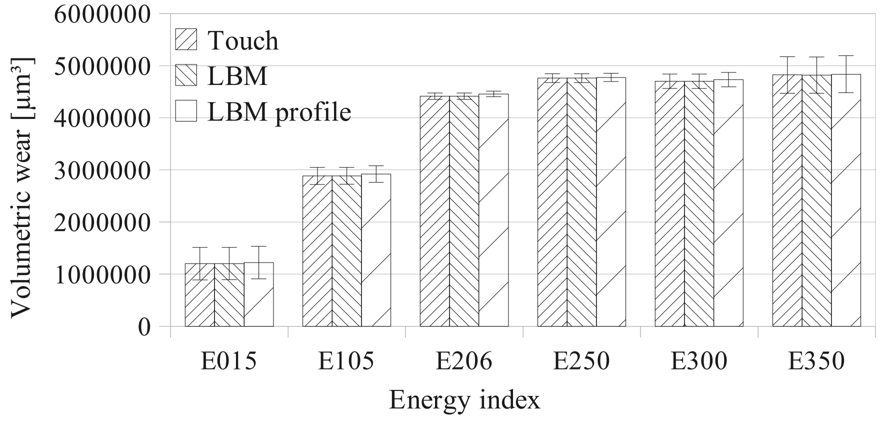
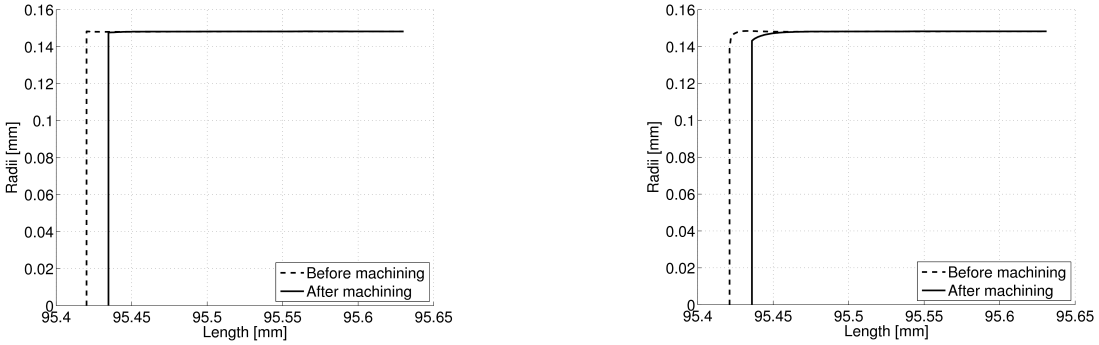


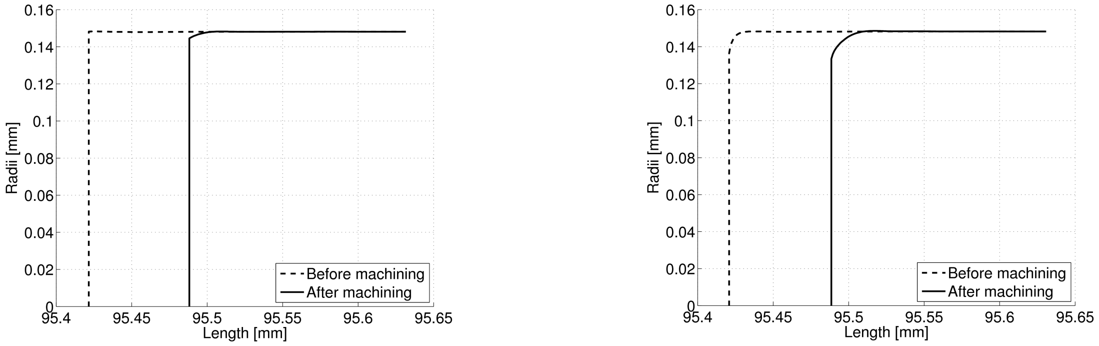
Fig. 1. Tool wear rate as the average of five experiment repetitions for each energy level

The machining layer thicknesses were relatively thin, specially when using low energy indexes but the corner wear of the electrode is still present. Lower discharge energy and thinner machining layer causes less corner wear (Fig. 2). It is clearly seen, that the corner wear on the electrode tip varies even when using the same energy index – the wear profile is not stable.



a) Energy index E015

b) Energy index E015



c) Energy index E300

d) Energy index E300

Fig. 2: Electrode profile acquired on machine by LSM system

In the present study, the electrode with a diameter of 0.3 mm was used, which is the biggest diameter used in micro EDM milling. In the case of smaller electrode diameters, the corner wear becomes more significant. For very small electrode diameters (down to 20 μm) the measurement of the linear wear is not sufficient for effective wear compensation, thus the volume wear has to be considered.

4. Conclusions

From the results presented above, the following conclusions can be drawn. To use Touch method to measure the linear wear, more than one measurement of the electrode length has to be performed before and after machining. If five measurements are performed and average value is considered as the electrode length, the use of LSM system does not lead to a significant improvement of linear wear measurement and consequently to the electrode wear compensation.

The corner wear of the electrode is significant also when very thin layers are machined. In order to accurately measure volumetric wear, the best result is obtained by acquisition of the electrode profile.

The corner wear is crucial when electrodes with small diameters are used. In that case the wear compensation based on linear wear measurements is no sufficient for effective wear compensation.

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