Micro EDM parameters optimisation

S. Bigot[a], J. Valentinčič[b,c], O. Blatnik[b], M. Junkar[b]

[a] *Manufacturing Engineering Centre, Cardiff University, Cardiff, UK, e-mail: bigots@cf.ac.uk*
[b] *Faculty of Mechanical Engineering, University of Ljubljana, Slovenia, e-mail: lat@fs.uni-lj.si*
[c] *Corresponding author*

Abstract

Electrical discharge machining (EDM) is an important process in the field of micro machining. However, a number of issues remain to be solved in order to successfully implement it in an industrial environment. One of these issues is the processing time. This paper investigates the optimisation of machining parameters for rough and fine machining in micro EDM. In one case, the parameters are selected to achieve the highest material removal rate (MRR). In the other case, the best surface roughness is targeted. Some of the main difficulties linked with micro EDM are caused by the high wear occurring on the electrode. The study focuses on a specific combination of electrode and workpiece material and proposes a typical method for micro EDM process optimisation.

Keywords: micro EDM, micromachining, roughing, finishing, micro holes and cavities

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1. Introduction

Over the next four years, the Microsystems market, including Micro-Structure Technologies (MST) and Micro-Electro-Mechanical Systems (MEMS), is predicted to grow at a rate of 16% per year from $12 billion in 2004 to $25 billion in 2009 across a spectrum of 26 MEMS/MST products [1]. Conventional processes are increasingly being improved for use in micro-machining. The most common processes are micro milling, laser machining and more specifically micro EDM, which is being applied in many micro applications [2].

In EDM, 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 evaporation and melting of the workpiece. Debris of material are removed by the resulting explosion pressure, enabling the machining of the workpiece [3]. The characteristics of the electrical discharge pulses are linked with a set of machining parameters, which control the energy and frequency of discharges and thus the power in the gap. Consequently, the chosen set of parameters affect the material removal rate (MRR), surface roughness and relative electrode wear rate. In the case of conventional sinking EDM, machining strategies using roughing and finishing paths are well established and a number of studies offer guidelines for machining parameters selection [4].

However, in micro EDM a number of issues remain to be solved. For instance, the processing time is significantly higher. The size of electrode used and the resulting high electrode wear makes conventional die-sinking methods inadequate. This has led to the development of a number of new EDM strategies for micro machining. One common approach is the micro EDM milling, where a cavity is produced using a single small electrode on a series of machining path [5].

This paper investigates the influence of various combination of machining parameters in micro EDM, in an attempt to optimise the MRR and surface roughness when using such approach, taking also into account the relative electrode wear.

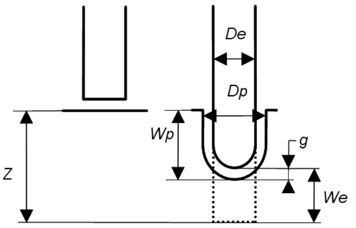

Fig. 1. Erosion process in drilling.

2. Experiment description

2.1. Machining set-up

The workpiece material selected for investigation was Tool steel P20. The electrode used was a tungsten carbide (WC) cylindrical rod with diameter *De*=0.170mm. The machining was performed using synthetic oil as dielectric.

Before each machining. the bottom of the electrode was EDM grounded flat. The rotating electrode was then used to drill a hole of diameter *Dp*, from the workpiece top surface down to a targeted depth Z=0.5mm. Figure 1 illustrates the drilling process affected by the wear, where *Wp* and *We* are the eroded lengths from the workpiece and electrode respectively and *g* is the bottom spark gap.

After all machining, the workpiece was cut along the middle of the holes using a wire EDM machine, allowing access to the holes profiles.

2.2. Design of experiments

In order to assess the effect of each machining parameter on the process, the Taguchi approach was used [6]. This method is a type of statistical technique called Design Of Experiments (DOE) that makes it possible to analyse the effect of more than one factor at the same time while reducing the number of experiment. Thus, using the Taguchi approach, the design of experiments and analysis of results can be done with less effort and expenses. However, since the method considerably reduces the number of experiments, quality loss of results could appear.

2.2.1. *Output functions*

In the proposed experiment, the main functions are material removal rate (MRR), electrode wear and surface roughness. MRR was calculated as a quotient of the volume *Vp* removed from the workpiece and the machining time. A rotating electrode was used to produce the holes, therefore their volumes can be estimated from their profiles. Digital images of the profiles were taken after machining and, based on each line of pixels composing the holes, the volumes were estimated using equation 1.

$$Vp = \sum_{i=1}^{N} \frac{\pi \cdot d_i^2}{4} \cdot K^3 \qquad (1)$$

where d_i is the diameter of the hole at the *i*-th line of pixels, *N* is the number of lines of pixels composing the hole and *K* is the size of a pixel in mm.

The reduction of the electrode length due to the wear (*We*) was measured on the machine. This was achieved by assessing the difference, before and after machining, of contact point in the z axis between electrode tip and workpiece top surface. The wear of the tool electrode is usually given as the relative electrode wear (ϑ), which is a quotient of the volume removed from the electrode *Ve* and the volume removed from the workpiece *Vp*. In this experiment, in order to facilitate computation, the corner wear was considered negligible. Therefore the geometry of the worn electrode could be assumed cylindrical and *Ve* was easily assessed as a function of *We*.

The roughness was measured in Ra on the holes profiles using a white light interferometer microscope. And, because the surfaces are not flat, an algorithm supplied with the microscope was used to compensate automatically for curvatures and tilts.

2.2.2 *Control factors*

One crucial step in the Taguchi method is the identification of the control factors and of their values considered for investigation. These values (or factor levels) should be placed very carefully, since the Taguchi method defines the significant and optimal parameters only within the selected ranges.

In this study, the control factors selected for optimisation were the machining parameters:

- Electrode polarity, which can be either positive or negative;
- Peak current (i_e), which gives the highest electric current that can occur during the discharge (if no capacitors is used);
- Ignition voltage (u_i), which is the voltage generated in order to ignite the discharge;
- Pulse-on time (t_i), which is the duration of the impulse generated by the impulse generator;
- Pulse-off time (t_o), which is the time between two impulses;
- Capacitance C of the capacitors, which is included in the circuit in order to accumulate electricity and to increase the discharge current;
- Two parameters related with the servo system, namely the reference voltage related with the size of the front gap and the gain of servo system that defines the reaction time of the servo system to the conditions in the gap.

Table 1 Parameters Levels

	i_e [A]	u_i [V]	t_i [ms]	t_o [ms]	C [nF]	gap	gain
lower limit	0.8	60	1	2.4	/	50	2
middle value	1.4	80	2.4	13	2.7	65	5
upper limit	1.8	100	5.5	56	19.4	80	9

For each parameter, apart from the polarity, three values were selected for investigation. The range of values was identified empirically, taking into account on one hand the lowest power that can be supplied by the machine generator and on the other hand the highest power that the electrode can take before burning out.

The lowest electrical power the machine is able to supply in the gap is determined by the smallest values of peak current (i_e = 0.8A), pulse-on time (t_i = 1ms), and capacitance (no additional C), which were therefore used as lower limits. Also, a longer pulse-off time induces lower power in the gap and consequently results in a lower MRR. Thus, the upper limit for this parameter should be relatively high. However, because the micro EDM is already a slow process, this upper limit (t_o = 56ms) was selected in order to allow low power in the gap while keeping an acceptable MRR. The ignition voltage plays a role only in the discharge formation phase, i.e. formation of the plasma channel in the gap. It influences the frontal gap, the higher the ignition voltage the greater the front gap. Its lowest value (u_i=60V) was selected as lower limit.

The highest electrical power that can be used for machining is determined by the electrode material and diameter. Past a certain limit the electrode behaves as a fuse and burns. In this investigation, the upper limits for peak current, pulse-on time, capacitance and ignition voltage and lower limit for the ignition voltage, which does not cause the burning of the electrode, were found empirically by trial and error.

The ranges of the two parameters of the servo system and ignition voltage were selected empirically (comp $\in$ [50,80] and gain $\in$ [2,9]). These values are machine specific and are not given in physical units.

The selected levels for the machining parameters are given in table 1.

2.2.3. *Set of experiments*

Based on Taguchi approach, the experiments can be defined using the orthogonal array. For this study, the L_{18} orthogonal array [6] was chosen, where 18 combinations of parameters are proposed for investigation.

Table 2 L_{18} orthogonal array

No. of	machining parameters								machining efficiency		
experi-ment	polarity	i_e [A]	u_i [V]	ti [μs]	t_0 [μs]	C [nF]	gap [-]	gain [-]	MRR [mm³/min]	ϑ(-) [–]	Ra [μm]
1	+	0.8	60	1.0	2	/	50	2	0.0003	1.6162	0.34
2	+	0.8	80	2.4	13	2.7	65	5	0.0006	3.0760	1.14
3	+	0.8	100	5.5	56	19.4	80	9	0.0008	2.0715	0.8
4	+	1.4	60	1.0	13	2.7	80	9	0.0003	3.0782	1.51
5	+	1.4	80	2.4	56	19.4	50	2	0.0010	1.7383	0.72
6	+	1.4	100	5.5	2	/	65	5	0.0007	0.7540	0.62
7	+	1.8	60	2.4	2	19.4	65	9	0.0016	0.7588	0.73
8	+	1.8	80	5.5	13	/	80	2	0.0004	1.9202	0.41
9	+	1.8	100	1.0	56	2.7	50	5	0.0004	3.6376	1.62
10	-	0.8	60	5.5	56	2.7	65	2	0.0011	0.2151	0.34
11	-	0.8	80	1.0	2	19.4	80	5	0.0020	0.2847	0.56
12	-	0.8	100	2.4	13	/	50	9	0.0009	0.1247	0.46
13	-	1.4	60	2.4	56	/	80	5	0.0006	0.1988	0.22
14	-	1.4	80	5.5	2	2.7	50	9	0.0014	0.2124	0.97
15	-	1.4	100	1.0	13	19.4	65	2	0.0018	0.2954	1.36
16	-	1.8	60	5.5	13	19.4	50	5	0.0007	0.3916	1.07
17	-	1.8	80	1.0	56	/	65	9	0.0007	0.1941	0.58
18	-	1.8	100	2.4	2	2.7	80	2	0.0021	0.2584	0.44

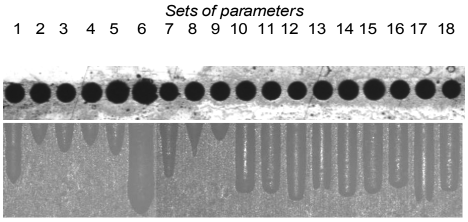

Fig. 2. Side and top view of the holes

The experiments were repeated three times, making a total of 54 machining. The values of the parameters for each machining are given in table 2 together with the average values of the obtained MRR, relative electrode wear and surface roughness.

3. Results and discussion

The first 18 holes are shown in Figure 2. From the picture, it can immediately be noticed that in contrast to conventional EDM machining, where positive polarity is preferable for machining hardened steel, negative polarity is more desirable in micro EDM.

3.1. Significant parameters

Based on the results shown in Table 2, the significance of each machining parameters to the MRR, relative electrode wear and surface roughness was calculated according to the ANOVA and F-test [7].

The principal of this method is to compare, for each output function, a calculated statistic F_0 for every machining parameter with a critical value derived from the Snedecor distribution [5], $F_{0.05}$ for parameters with three levels and $F_{0.005}$ for parameters with two levels. Machining parameters having F_0 greater than their critical value are considered significant to the main function and marked with asterisk (*) in the table 3.

In the given range of machining parameters, the polarity appears to be significant to the MRR and to the relative electrode wear, while the capacitance C shows significance to the MRR and the surface roughness.

3.2. Optimal parameters levels

According to the Taguchi method, in order to find the optimal machining parameters, the signal-to-noise ratio (S/N) [6] of each machining parameter level must be assessed for each output function. The highest S/N of the considered machining parameter levels indicates an optimal level.

The S/N values for MRR, relative electrode wear and surface roughness are given in Figure 3, 4 and 5 respectively.

Table 3 Machining parameters significance

	MRR		ϑ		Ra	
	F_0	$F_{0.005}$	F_0	$F_{0.05}$	F_0	$F_{0.05}$
polarity	9.76*	5.13	98.99*	5.13	1.38	5.13
i_e	0.02	4.46	0.11	4.46	0.99	4.46
u_i	2.03	4.46	0.17	4.46	0.80	4.46
t_i	1.83	4.46	1.36	4.46	1.47	4.46
t_o	2.79	4.46	1.93	4.46	1.81	4.46
C	5.59*	4.46	2.58	4.46	4.97*	4.46
gap	2.72	4.46	1.03	4.46	0.95	4.46
gain	0.43	4.46	0.91	4.46	1.37	4.46

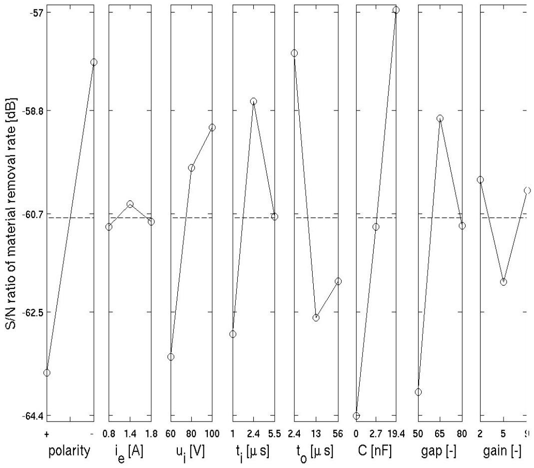

Fig. 3. MRR S/N ratios

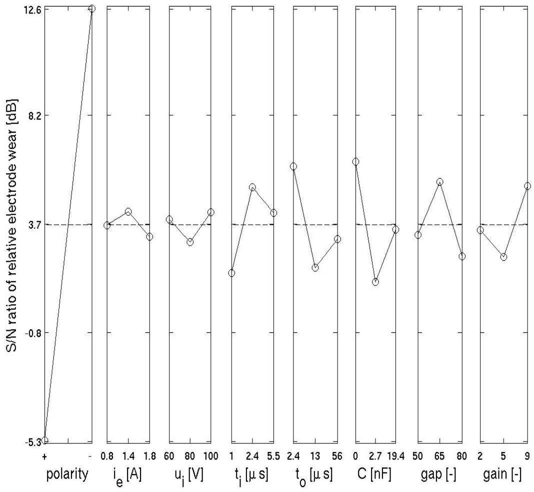

Fig. 4.Electrode wear S /N ratios

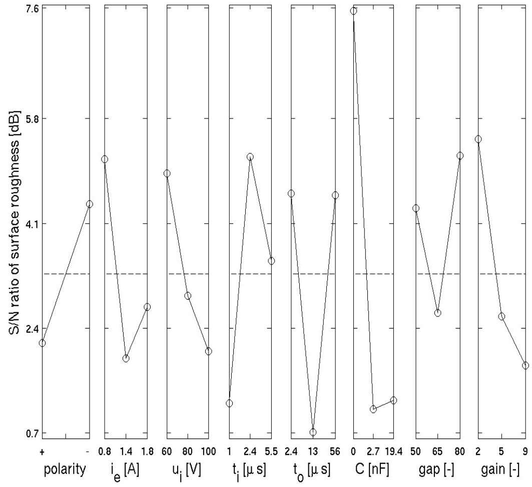

Fig. 5. Surface roughness S/N ratios

Table 4 Optimal machining parameters

	machining parameters								machining efficiency		
	polarity	i_e	u_i	ti	t_0	C	gap	gain	MRR	ϑ(-)	Ra
optimum		[A]	[V]	[µs]	[µs]	[nF]	[-]	[-]	[mm³/min]	[–]	[µm]
MRR	-	1.4	100	2.4	2.4	19.4	65	2	0.0024	0.1482	0.53
ϑ	-	1.4	100	2.4	2.4	/	65	9	0.0012	0.1409	0.22
Ra	-	0.8	60	2.4	2.4	/	80	2	0.0009	0.8579	0.20

Based on these figures, the theoretical optimal set of machining parameters can be assessed and are shown in Table 4.

Using these three optimal sets of parameters, another machining was performed on the workpiece and the resulting MRR, relative electrode wear and surface roughness can be found in Table 4.

The MRR achieved with the optimal set of machining parameters defined by the Taguchi method, appears to be better than the best results obtained previously. This is also the case for the surface roughness, where the optimal set of parameters gives the smoothest surface.

Thus, these two set of parameters can be used for roughing and finishing strategies in micro EDM, when using a similar electrode/workpiece combination.

The roughing technology is achieving a MRR three times greater than the finishing whereas the surface roughness it produces can be reduced by more than half using the finishing technology (table 4).

This should allow an improvement of the micro EDM processing time while producing smoother surfaces.

In cases where the electrode wear should be reduced to its minimum (to avoid frequent tool change for instance), the machining parameters optimised for the lowest electrode wear should be considered. However, the result obtained does not appear to be the best. The set of parameters number 12 (Table 2) seems to give a better result. This can be explained by the method used for electrode wear measurement, where only the length of the electrode wear was measured while neglecting the corner wear. Thus, the electrode volume wear assessment should be improved.

3. Conclusion

In this study, a method for machining parameters optimisation in micro EDM was proposed. Two sets of optimum parameters for roughing and finishing in micro EDM were successfully defined for a specific electrode/workpiece combination.

Further investigation will look at the improvement in processing time and surface roughness brought by using these sets of parameters when in a micro EDM milling strategy.

In addition, the results showed that in micro EDM, negative polarity is preferable for both roughing and finishing and that in the given range of machining parameters the capacitance is the most significant parameter for MRR and surface roughness.

Future work will focus on the use of various materials, electrode diameters and cavities shapes.

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