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Tool electrode geometry and process parameters influence on different feature geometry and surface quality in electrical discharge machining of AISI H13 steel

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Abstract Electro discharge machining process (EDM) is frequently used when machining of high complex and accurate features is required. Indeed, it is specially recommended for hard materials and micro-machined features. However, due to the process nature, there is still incomprehension on process parameters influence at the final quality features, ending up by lower productivity and quality ratios. On the other hand, fashioning and re-shaping of required electrodes for each feature are time consuming phases and the number of stored electrodes is very high. Therefore, in order to increase the global EDM process productivity, quality and flexibility, standardized simple electrode shapes, capable to machine different features, must be found. This study presents the influence of the main EDM process parameters and different tool geometries on basic process performance measures. A set of designed experiments with varying parameters such as pulsed current, open voltage, pulse time and pulse pause time are carried out in H13 steel using different geometries of copper electrodes. In addition, material removal rate , surface roughness and different dimensional and geometrical micro-accuracies are analyzed through statistical methods. Results help to select appropriate EDM process parameters to machine parts depending on product requirements.

Keywords EDM · MRR · Surface roughness · Process parameters · Accuracy · ANOVA

Introduction

Electro discharge machining (EDM) process is based on thermal energy, which comes through innumerable sparks between the tool electrode and the workpiece. Electrical discharge machining (EDM) processes are now gaining in popularity, since many complex 3D shapes can be machined using a simple shaped tool electrode. The pair of electrodes are sunken into a dielectric fluid and open voltage is applied. During the process, both parts are placed very close one from the other (gap distance is in the order of μm), to permit plasma channel creation between the anode and the cathode. When gap width between the tool and the electrode achieves the maximum sparking gap width, a micro-conductive ionized path appears and the electric spark occurs achieving temperatures up to 15.000 or 20.000°C (Jeong and Min 2007). Conductive material is then molten and/or vaporized from the workpiece.

The absence of direct contact between the tool and the electrode caused by the nature of the process avoid common process problems such as mechanical stresses and vibrations caused by conventional machining processes (Groover 1996; Garcìa Navas et al. 2008). Although EDM is mainly used in electrically conductive work materials, the usage of certain additives (such as titanium carbide (TiC), titanium boride (TiB_2) or zirconium boride (ZrB_2), among others) permits initially non-conductive materials to be machined by EDM process. Collateral effects like the diminution of mechanical resistance are then compensated with other additives (Puertas and Luis 2004).

EDM process is increasing its presence partially due to works developed by many researchers described by Ho and Newman (2003), Ho et al. (2004) and Pham et al. (2004). As many authors have reported, higher values of current discharge and open voltage clearly increase material removal

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rate (MRR), electrode wear ration (EWR) and surface roughness (Salman and Kayacan 2008; Ferreira 2007; Liu et al. 2008), also at micro-machining scale.

Depending on the kind of material used and other requirements, positive or negative polarity can be applied. This is one of the most important process parameters that affect EWR, surface roughness, MRR and expansion of micro-holes (Yan et al. 1999). There are several authors who has researched EDM process to be applied on hard materials or materials which are difficult to cut by using machining processes such as Wansheng et al. (2002) who have constructed EDM equipment to machine drill holes on titanium alloys or Khanra et al. (2007) who studied the performance of composite tool compared with the cupper tool.

Process modelling is an important issue to cheapen manufacturing processes because it facilitates the process basics understanding for optimizing the final process performance. However, the complex nature of the EDM process interaction between the electrode (tool) and the workpiece material does not facilitate this task. To solve this question many authors have applied statistic methods such as analysis of variance (ANOVA) models and S/N ratios in order to analyze and optimize the process performance measures (process outputs) in comparison of the process parameters (process inputs). Taguchi method is very effective to deal with response influenced by multi-variables, which is clearly the case of EDM process. This method focuses on minimizing the effect of causes of variation. In general, it provides a significant reduction in the size of experiments, thereby speeding up the experimental process. The signal-to-noise ratio is a quality ratio that permits to evaluate the effect of changing a particular design parameter on the performance of the process (Lin et al. 2006; Sundaram et al. 2008; Pradhan et al. 2008). However, there are other research works which studies EDM processes by using other modelling tools. Kumar (2008) developed mathematical models to compute thermal stresses based on temperature distribution function. Models with artificial neural network algorithms are also well used such as to predict surface roughness (Markopoulos et al. 2008; Tsai and Wang 2001), to determine processing conditions automatically and to calculate processing parameters automatically (Fenggou and Dayong 2004). Finally, Das et al. (2003) has used finite element modelers to predict the transient temperature distribution and residual stresses in EDM processes.

EDM-workpiece material interaction is influenced by many process parameters and considered highly non-linear. There are a number of operational parameters which must be set when manufacturing process is done. These operation parameters are variable and can be adjusted in areas to optimize the desired quality of the machined features. However, there have been many studies aimed at systematically investigating the influence of process variables during EDM machining (Kiyak and Çakır 2007; Guu and Hou 2007; Mahardika et al. 2008).

Considering all those operational parameters, it is highly difficult to model the influence of them on resultant workpiece geometry and surface quality using conventional methods. Usually, the operator selects them based on experience or designs appropriate experiments to determine somewhat reasonable parameter combination for the desired results. But, this trial-and-error approach is high costly in time and labor. Especially when a prototyping batch is carried out and due to the short lead time constraints the results cannot be fully optimized.

There are several research works which mainly deal with how process parameters affect the quality of the resultant surfaces or geometrical features using experimental and analytical tools. For instance, Mahardika et al. (2008) who discussed the effect of using different levels of total energy of discharge pulses, discharge pulse number, average discharge pulse energy, discharge pulse density, and tool electrode wear on final product. Singh et al. (2004) studied different tool materials effect on EDM of hardened steel.

There are also some research works which combines or integrates technologies to enhance EDM properties. Wansheng et al. (2002) bring ultrasonic vibration into EDM process, and can fabricate and measure micro-electrodes online. Similar works to produce holes combined with grinding processes are used by Liu et al. (2006).

This paper investigates the possible interactions between common process parameters and final quality process measurements through ANOVA and S/N ratios. In addition, different tool geometries are tested, compared and validated to machine the same feature to study the reduction of tool-electrode geometries storage in workshops. Results given in this paper helps to select appropriate EDM parameters when user designs process planning based on product requirements such as geometrical features and surface roughness.

Experimentation

Although EDM technology has been widely investigated, actual industry capabilities depend on process efficiency, which can still be improved a lot. Experiments are carried out in order to find process parameters and electrode geometry (inputs) relations with productivity performance measures (MRR) and micro-dimensional and geometrical accuracies. Therefore, a groove of 3 mm width and 1 mm depth is used as experimental target feature. Next, the different experimentation steps, material characteristics and design of experiments (DOE) are presented.

Methodology

Different electrode geometries are initially designed in CAD/CAM applications (Fig. 1) and then machined in a Deckel Maho© 64V linear machining center. Four different options have been considered: square, triangle, circle and rectangle due to their simplicity and to their different machining contact area. Erowa© clamping device is aligned with machine's *X*, *Y* and *Z* axis using a dial indicator with 1 μm accuracy to provide a fine adjustment between the machined electrodes axis and the subsequent machining path in the EDM machine.

The next step is to achieve a better electrode surface quality (lower Ra) through a final grinding phase. GER© SCA 60/40 grinding machine with a grinding wheel (Ref: 88A46J7V217) and Erowa© clamping device have been used.

Finally, electrode measures are obtained using Mitutoyo© Rugometer (Mod: Surfest SV-2000). Figure 2 presents the grinding phase and the following verification step. The surface roughness value range was found to be between 0.26 and 1.12 μm.

Once all electrodes are manufactured and measured, experiment machining step is ready to be initiated. Twenty four experiments are carried out using ONA© DB-300 machine (Fig. 3) consecutively in order to minimize alignment and repeatability errors.

During the experimentation, total process time is measured to calculate MRR. When all grooves are done, machined surface roughness and micro-accuracies are measured. Mitutoyo© CMM machine (Crysta Apex 544) with an error lower than 1.9 μm (certified by ENAC) is used (Fig. 4), as well as the Mitutoyo Rugometer previously used in initial electrode surface roughness measurement.

The analyzed geometrical features are groove slope (slope) and deviation between entrances and exits (DVEE). The first time is explained in Fig. 5. Machined surface slope is obtained considering the angle between the reference plane and the machined surface, which is caused by accumulative axial wear during the process. Using CMM machine, the reference plane is measured by four points and the groove surface is measured by 12 points along the machining path. These points are also used in depth dimensional accuracy measurement.

On the other hand, DVEE parameter (also known as taper angle) is normally used to measure the difference between top and bottom diameters in micro-hole EDM machining (Liu et al. 2005; Lin et al. 2006). It is mainly caused by electrode radial wear and debris accumulation in some areas (Yan et al. 1999), provoking a smaller diameter at the bottom

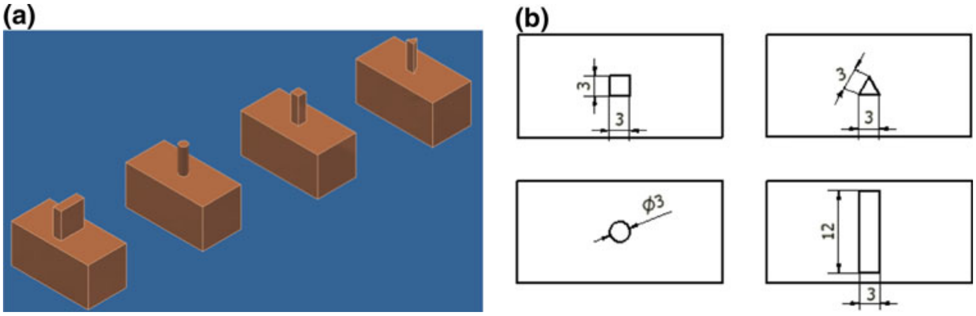


Fig. 1 **a** Presentation of the 4 electrode geometries. **b** Electrodes plan (units are in mm)

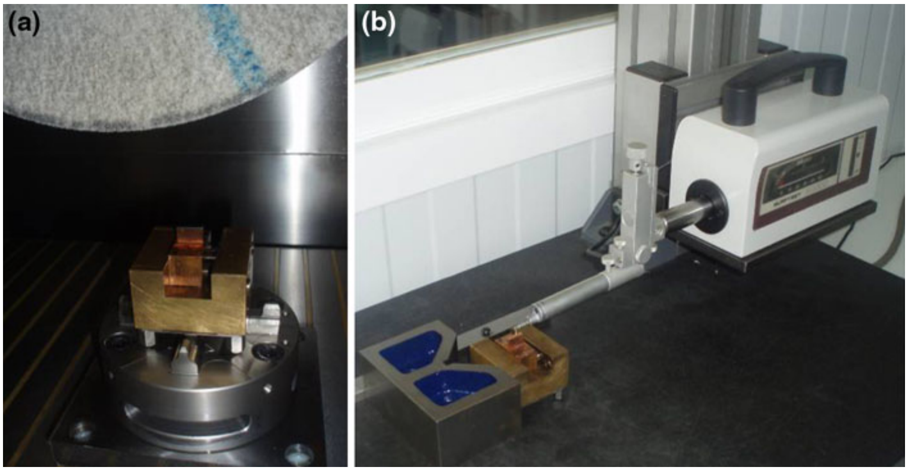
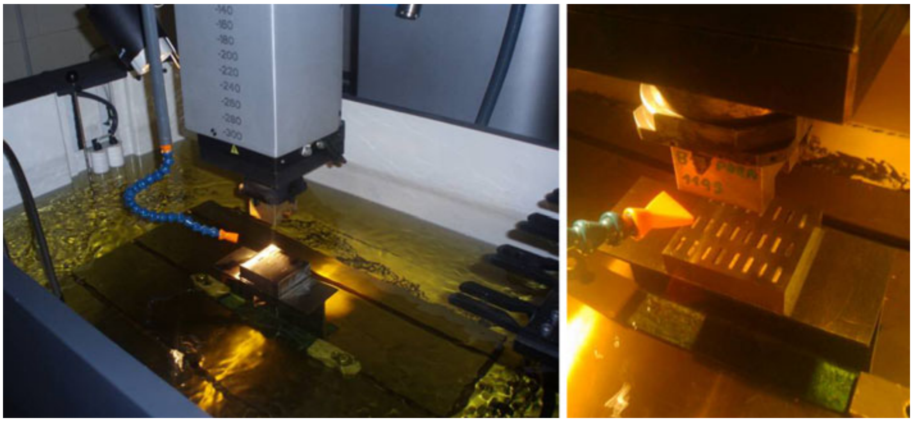


Fig. 2 **a** Electrode grinding. **b** Rugometer measurements of the electrode

Fig. 3 EDM process using ONA© DB-300



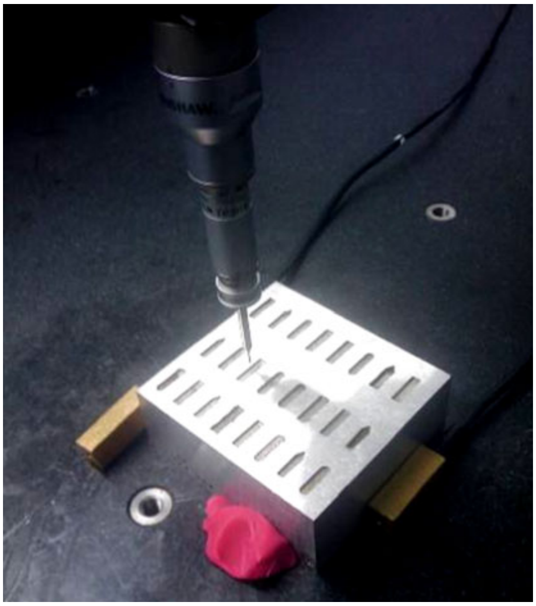


Fig. 4 MMC machine measurements

of the hole. However, in this paper some modifications have been considered regarding DVEE parameter. In this case, XY plane becomes the reference plane instead of ZX plane, as seen in Fig. 6a and b. Therefore, through measuring 12 points between both edges (obtaining the parallelism along the machined groove edges), the DVEE angle is calculated. In addition, these points are also used in order to calculate the width of the feature.

These two geometrical accuracies are focus of interest due to its clear relation with tool wear. Indeed, slope angle and DVEE can be easily associated with axial and radial wear respectively, causing quality problems on the final machined feature. For this reason, it is very interesting to analyze different electrode shapes, which will be eroded differently, in order to obtain better quality in the process.

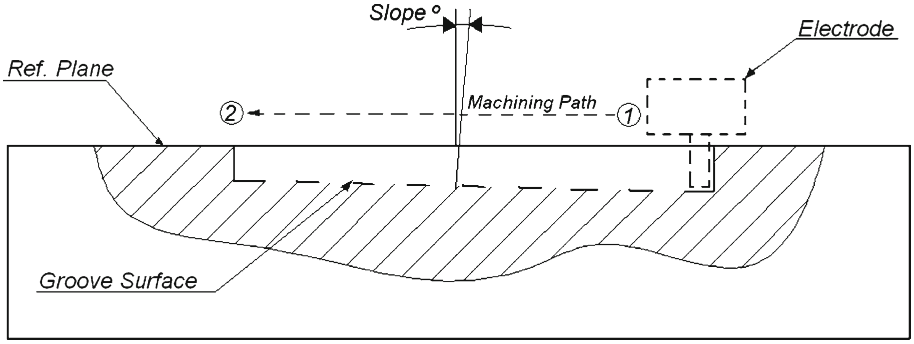
Finally, data treatment is done through different statistical methods (ANOVA, S/N ratios and statistical boxplots) to analyze final performance measures and their level of dependence on EDM process parameters and tool geometry.

Materials

In mould and die manufacturing industry, AISI H13 steel is widely used in common applications, reason why it has been chosen in this study. Its composition is presented in Table 1.

On the other hand, electrode tool material is electrolytic copper because it offers a good overall behavior in steel machining. Higher MRR with low relative tool wear (RTW) and good surface roughness can be achieved (Pham et al. 2004), offering a good overall performance. Tool electrode and workpiece hardness are measured as 77 HRB and 95 HRB respectively (tested in a Hoytom© durometer, model Minor-69).

Fig. 5 Slope between reference plane and machined groove surface



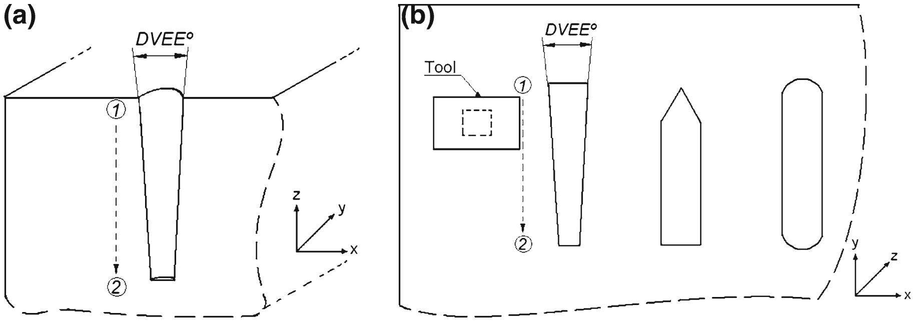


Fig. 6 **a** Conventional approach for DVEE. **b** Adapted approach

Table 1 AISI H13 steel chemical composition (UNE-EN ISO 4957:2000 Norm)

Composition	Cr	Mo	Si	V	C	Mn	<P	<S
Weight (%)	4.80–5.50	1.20–1.50	0.80–1.20	0.85–1.15	0.35–0.42	0.25–0.50	<0.03	<0.03

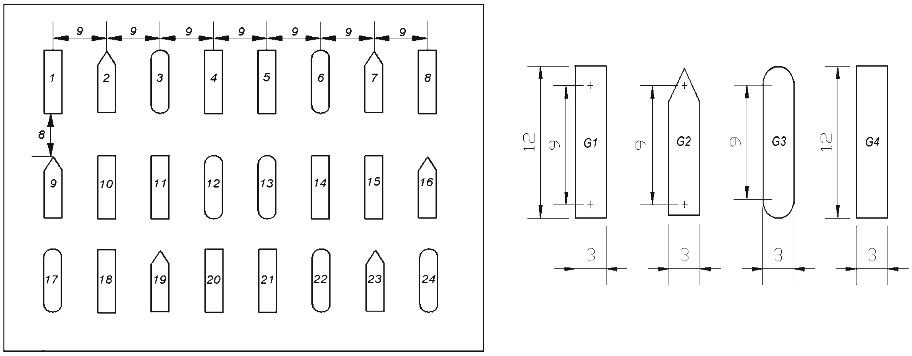


Fig. 7 Workpiece design (units are in mm)

Design of experiments

To determine influential parameters for EDM groove machining, 24 experiments have been carried out based on Taguchi Ortogonal Array OA $_{16}(4^5)$ has been chosen in order to have representative data (Logothetis and Wynn 1989). Figure 7 illustrates the 24 experiments layout. Each machined groove is made by inducing a 9 mm path to the tool electrode, except for the rectangle shaped electrode, which only penetrates the workpiece vertically.

Open voltage, current discharge, pulse-on and pulse-off times are influential parameters to the common performance measures like MRR and surface roughness (among others) (Salman and Kayacan 2008; Liu et al. 2005; Ghoreishi and Tabari 2007). In addition, tool geometry is also considered to identify its influence on these process performance measures and especially on final accuracies. Table 2 presents the five different EDM process parameters chosen and their levels.

Table 2 EDM process parameters and levels

Parameter	Level			
	L1	L2	L3	L4
P1. Open voltage (V)	80	120	160	200
P2. Intensity (A)	4	5	6	7
P3. T_{on} (μs)	25	50	100	200
P4. T_{off} (μs)	3.2	6.4	13	25
P5. Tool geometry	G1□	G2△	G3○	G4▭

Table 3 Constant EDM process parameters

Parameter	Level
Polarity	+
Servo	70
Capacitors	0
Dielectric flow (l/min)	4.6
Working time (s)	1.5
Pause time (s)	0.5

Table 4 Experimental results and respective S/N ratios of the 24 experiments

						Real values						*S/N ratios [dB]*					
Groove	**[V]**	**[A]**	**T_{on}[µs]**	**T_{off}[µs]**	**Tool**	**Ra[µm]**	**MRR[mm^3/min]**	**Depth[mm]**	**Slope[']**	**Width[mm]**	**DVEE[']**	**Ra**	**MRR**	**Depth**	**Slope**	**Width**	**DVEE**
1	200	4	25	3,2	1	1,898	13,171	1,0527	15,92	3,0714	17,85	-5,566	-7,828	17,576	-24,039	20,466	-25,033
2	200	6	50	6,4	2	3,099	16,134	1,0609	38,43	2,8699	40,85	-9,824	1,302	17,643	-31,693	19,877	-32,224
3	200	8	100	13	3	4,741	21,092	1,0870	15,62	3,0637	15,80	-13,517	3,049	17,854	-23,874	20,444	-23,973
4	200	12	200	25	4	7,551	26,486	1,0449	13,43	3,1970	11,68	-17,560	1,692	17,511	-22,562	20,814	-21,349
5	160	4	50	13	4	3,589	13,931	1,0711	23,15	3,1339	8,08	-11,100	0,656	17,726	-27,291	20,641	-18,148
6	160	6	25	25	3	2,945	8,489	1,0007	21,27	3,0247	22,53	-9,382	1,617	17,136	-26,555	20,333	-27,055
7	160	8	200	3,2	2	2,998	66,711	1,1540	8,98	2,9469	79,47	-9,537	-18,745	18,374	-19,066	20,107	-38,004
8	160	12	100	6,4	1	6,743	14,830	1,1079	2,00	3,1440	4,57	-16,577	10,940	18,020	-60,206	20,669	-13,198
9	120	4	100	25	2	2,513	39,793	1,0093	1,85	3,2555	25,92	-8,004	-8,968	17,210	-53,434	20,972	-28,273
10	120	6	200	13	1	4,148	48,216	1,0808	22,28	3,1442	0,53	-12,357	-10,585	17,804	-26,958	20,669	5,515
11	120	8	25	6,4	4	4,978	5,022	0,9662	45,92	3,5336	5,05	-13,941	15,232	16,831	-33,240	21,684	-14,066
12	120	12	50	3,2	3	5,065	9,871	1,0174	6,12	3,4620	31,38	-14,092	18,606	17,279	-15,735	21,506	-29,933
13	80	4	200	6,4	3	2,854	70,077	1,0701	27,48	3,0608	28,42	-9,109	-15,127	17,718	-28,780	20,436	-29,073
14	80	6	100	3,2	4	3,747	26,688	0,9779	11,00	3,2196	19,42	-11,474	-4,877	16,935	-20,828	20,875	-25,765
15	80	8	50	25	1	4,337	11,528	1,0539	10,55	3,0911	13,07	-12,744	9,518	17,585	-20,465	20,522	-22,326
16	80	12	25	13	2	8,105	3,084	0,8409	91,40	2,0535	610,27	-18,175	19,879	15,624	-39,219	16,969	-55,710
17	120	4	50	3,2	3	5,492	9,104	1,0616	66,38	3,0710	38,75	-14,795	-19,103	17,649	-36,441	20,465	-31,765
18	160	5	200	13	1	4,006	49,925	0,8049	28,30	3,1948	6,08	-12,054	-10,591	15,244	-29,036	20,808	-15,678
19	80	6	100	6,4	2	5,183	19,293	1,0232	34,30	2,8193	52,28	-14,292	6,908	17,329	-30,706	19,722	-34,367
20	200	4	200	3,2	4	1,641	121,876	0,9698	13,80	3,2822	10,32	-4,302	-14,005	16,863	-22,464	21,043	-20,274
21	120	6	100	6,4	1	5,324	18,782	1,0571	12,85	3,1497	9,78	-14,525	6,526	17,612	-22,178	20,685	-19,807
22	160	7	200	25	3	8,192	24,414	0,4519	23,68	3,2696	45,00	-18,268	19,362	10,230	-27,488	21,009	-33,064
23	80	7	100	25	2	7,271	13,753	1,0163	18,12	2,5887	97,17	-17,232	16,144	17,270	-25,163	18,981	-39,751
24	200	7	25	3,2	3	5,105	4,897	1,0053	38,97	3,0620	22,58	-14,160	5,288	17,175	-31,815	20,439	-27,075

The rest of EDM parameters, presented in Table 3, must be kept constant during the experimentation to ensure a right comparison between the 24 tests.

Statistical methods have been applied to analyze the output data. In this case, ANOVA has been used over the S/N ratios of each value in order to identify the influential process parameters on certain performance measures.

The loss function used in the Taguchi method is transformed into a signal-to-noise ratio (S/N ratio) to normalize the different output values from the experimental data. Three different categories are used to classify the type of ratio to be applied depending on value characteristics. Therefore, “higher the better”, “lower the better” and “nominal the best” parameters are identified and its respective S/N ratios are applied following Eqs. 1–3 (Logothetis and Wynn 1989).

$$\text{Higher the better: } L_{ij} = 1/n \sum_{i=1}^{n} 1/y_{ij}^2 \quad (1)$$

$$\text{Smaller the better: } L_{ij} = 1/n \sum_{i=1}^{n} y_{ij}^2 \quad (2)$$

$$\text{Nominal the best: } L_{ij} = 10 \times \mathrm{Log}_{10}\left(y_{ij}^2/\sigma^2\right) \quad (3)$$

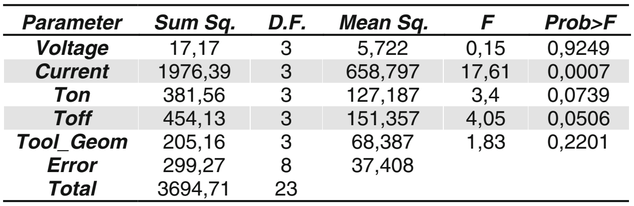
where L_{ij} is the loss function of the ith performance characteristic in the jth experiment, n the number of data, y_{ij} is the value of the ith performance characteristic in the jth experiment, and σ is the standard deviation of the data.

Next, the respective S/N ratio is calculated as follows in Eq. 4:

$$\text{S/N ratio: } n_{ij} = -10 \times \mathrm{Log}_{10}\left(L_{ij}\right) \quad (4)$$

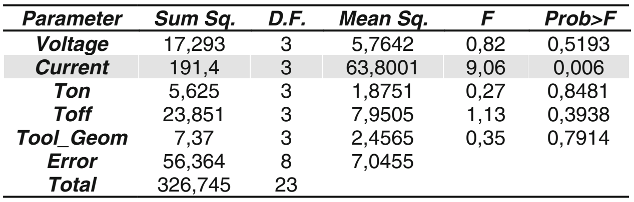
where n_{ij} is the S/N ratio of the ith performance characteristic in the jth experiment (Sundaram et al. 2008; Pradhan et al. 2008; Yan 2000).

Table 5 ANOVA for MRR



Parameter	Sum Sq.	D.F.	Mean Sq.	F	Prob>F
Voltage	17,17	3	5,722	0,15	0,9249
Current	1976,39	3	658,797	17,61	0,0007
Ton	381,56	3	127,187	3,4	0,0739
Toff	454,13	3	151,357	4,05	0,0506
Tool_Geom	205,16	3	68,387	1,83	0,2201
Error	299,27	8	37,408		
Total	3694,71	23			

Table 6 ANOVA for Ra



Parameter	Sum Sq.	D.F.	Mean Sq.	F	Prob>F
Voltage	17,293	3	5,7642	0,82	0,5193
Current	191,4	3	63,8001	9,06	0,006
Ton	5,625	3	1,8751	0,27	0,8481
Toff	23,851	3	7,9505	1,13	0,3938
Tool_Geom	7,37	3	2,4565	0,35	0,7914
Error	56,364	8	7,0455		
Total	326,745	23			

Table 7 ANOVA for slope

Parameter	Sum sq.	df	Mean sq.	F	Prob > F
Voltage	162.91	3	54.303	0.81	0.5253
Current	37.76	3	12.587	0.19	0.9025
T_{on}	441.39	3	147.13	2.18	0.168
T_{off}	217.14	3	72.381	1.07	0.4133
Tool_Geom	136.06	3	45.355	0.67	0.5925
Error	539.4	8	67.425		
Total	1500.84	23			

Table 8 ANOVA for depth

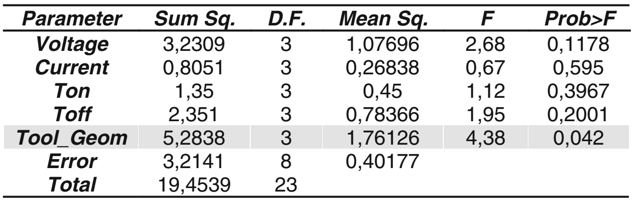
Parameter	Sum sq.	df	Mean sq.	F	Prob > F
Voltage	2.7506	3	0.91688	0.2	0.8914
Current	3.2008	3	1.06692	0.24	0.8687
T_{on}	4.2154	3	1.40514	0.31	0.817
T_{off}	2.3673	3	0.7891	0.17	0.9105
Tool_Geom	1.9991	3	0.66637	0.15	0.9284
Error	36.1234	8	4.51542		
Total	58.6942	23			

Results and discussion

All 24 experiments have been carried out following the process parameters listed in Tables 2 and 3.

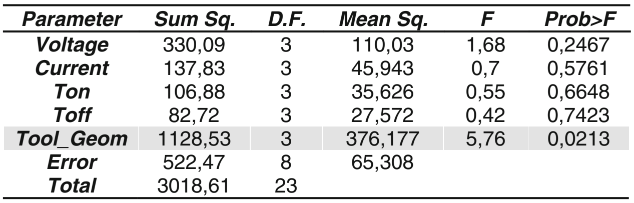
Table 4 shows final results of five input variables (voltage, current, pulse-on, pulse-off and tool shape) and six output measurements with their respective calculated S/N ratio

Table 9 ANOVA for width



Parameter	Sum Sq.	D.F.	Mean Sq.	F	Prob>F
Voltage	3,2309	3	1,07696	2,68	0,1178
Current	0,8051	3	0,26838	0,67	0,595
Ton	1,35	3	0,45	1,12	0,3967
Toff	2,351	3	0,78366	1,95	0,2001
Tool_Geom	5,2838	3	1,76126	4,38	0,042
Error	3,2141	8	0,40177		
Total	19,4539	23			

Table 10 ANOVA for DVEE



Parameter	Sum Sq.	D.F.	Mean Sq.	F	Prob>F
Voltage	330,09	3	110,03	1,68	0,2467
Current	137,83	3	45,943	0,7	0,5761
Ton	106,88	3	35,626	0,55	0,6648
Toff	82,72	3	27,572	0,42	0,7423
Tool_Geom	1128,53	3	376,177	5,76	0,0213
Error	522,47	8	65,308		
Total	3018,61	23			

(Ra, MRR, Depth, Width, Slope and DVEE). Considering Eqs. 1–3, MRR is treated as "higher the better" variable, whereas Ra, slope and DVEE are "lower the better" parameters and finally, width and depth are considered as "nominal the best". Tables 5, 6, 7, 8, 9 and 10 resume the results of the ANOVA analysis applied to the six selected process quality measurements. In order to identify the most influential process parameters, variables with probability values lower than 0.05 are considered (shadowed in Tables 5, 6, 7, 8, 9, 10 with). Indeed, the results reveal that current parameter clearly affects MRR and Ra. In addition, T_{off} also becomes an important parameter for MRR although its *p*-value is slightly higher than 0.05. Regarding on tool geometry, its influence is basically focused on radial tool wear, ending up by affecting both width and DVEE parameters. Finally, no clear relation between input parameters and slope and depth measurements has been found.

In addition, statistical box-plots of the reliable relations found in ANOVA analysis are presented in Fig. 8 to study their interactions.

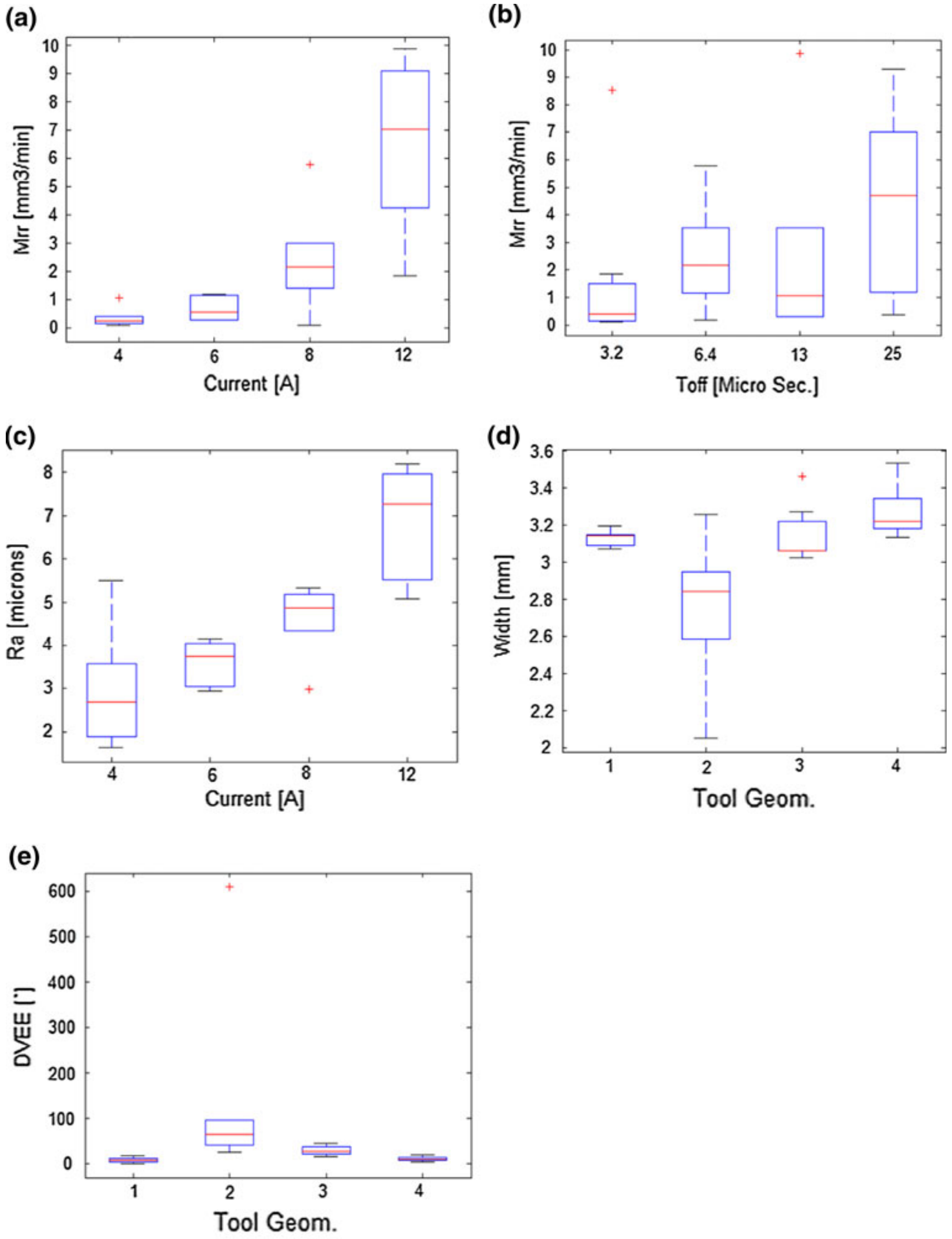


Fig. 8 Statistical Box-plot of **a** Current versus MRR. **b** T_{off} versus MRR. **c** Current versus Ra. **d** Tool geometry versus width and **e** Tool geometry versus DVEE

Figure 8a reveals that higher values of current discharge produce higher MRR values although a higher dispersion of the values is also achieved. Figure 8b presents confusing results due to the great deviation between measures. Therefore, T_{off} influence must be considered depending on the other parameters and their interaction should be further studied.

Figure 8c offers similar results to Fig. 8a. Thus, the surface roughness increases in accordance to the current discharge level. As it is well known, current discharge clearly affects MRR and surface roughness (Kiyak and Çakır 2007; Guu and Hou 2007; Özgedik 2006).

Figure 8d and e demonstrate the great impact of the tool geometry on the final feature accuracy. Target width of 3 mm is nearly achieved by square electrodes and, in second term, by round and rectangle electrodes. On the other hand, square and rectangle electrodes are likely to be the best solutions when long tool paths are required due to their better radial tool wear ratio demonstrated by their lower levels of DVEE angle. Finally, triangle electrodes do not perform well and they cannot be used for complex geometries machining.

Conclusions

Influence of different process parameters (pulse current, open voltage, pulse time and pulse pause time) as well as tool electrode shape on several performance measures (MRR, surface roughness, depth, width, slope, and DVEE) has been analyzed for copper electrode and AISI H13 steel workpiece in sinking type EDM process using statistical tools.

Obtained ANOVA tables reveal most clear interactions among input and output parameters in EDM sinking process. MRR and surface roughness increase with discharge current. Pulse-off variation affects MRR, but its behavior is not lineal due to the interactions with other process parameters, which must be deeply analized in further studies. Tool geometry is a critical choice when different features are machined. Square and rectangle electrodes present better radial and axial wear ratios. Therefore, these geometries are likely to be the best option for flexible tool electrode shape design.

To summarise, presented results permit to better understand common process parameters influence on process performance measures and machined feature accuracies, facilitating process planning tasks in EDM field. Analysis of tool geometry behavior must permit storage, time and cost reduction associated to tool electrodes in workshops creating different features with simpler and more standardized geometries.

The results obtained show how to select suitable process parameters to predict geometrical features and surface roughness patterns and can be utilized in process planning for micro machining with EDM technology.

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