International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

Optimization of Various Performance Parameters in Micro Electrical Discharge Machining Process Using Taguchi Method

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Abstract: ***Now a days, the expectation is to manufacture high-quality products with low cost within a very short duration. In order to produce products with a desired quality by machining, in the influence of various parameters such as the tool wear rate, surface roughness and material removal rate should be considered.This paper presents the methodology of the Taguchi method to find the optimum parameters for obtaining a higher MRR, with a lower TWR andthe minimum surface roughness in the micro-EDM process. The micro electrical discharge machining process (µ-EDM) has proved to be an appropriate a nonconventional and a nontraditional machining method for machining accurate and complex 3-D structural micro-parts and micro-tools which are very difficult to be produced by conventional machining methods. Which Based on ANOVA, pulse on time is found the significant factor, which affects micro electro discharge machining process. Optimized process parameters simultaneously leading to a higher MRR, lower TWR and SR are then verified through a confirmation experiment.***

Keywords: µ-EDM, Multiple performance parameters, Taguchi method, ANOVA, GRA.

1. Introduction

Several researchers focused on their efforts on producing micro components and micro-systems to meet industrial demand for miniaturization. When producing a micro-components, it is very critical to achieve high form accuracy and very precise dimensions. However, it is a challenge to produce typical micro components such as micro-dies made by high-hardness materials using conventional machining methods such as micro-turning or micro-milling. This type of problem can be easily solved by one of the methods, such as the µ-EDM. The main advantage of this type of method is that machining process is independent of the hardness of the work piece. In fact, very-very hard materials are better candidates for µ-EDM. Therefore, it has become a most important method for machining very micro and sub-micro-components of hard materials and electrically conductive materials. In order to use the µ-EDM in the manufacturing industries more effectively, many researchers all over the world have initiated such research works to overcome by all the characteristics parameters that influence the performance of the machining process .The MRR, the TWR and the surface roughness are the most significant parameters to be considered to obtain the desired machining-performance during the µ-EDM process. The capacitance, feed rate, gap voltage and threshold are the such machining parameters affecting the performance measures. Among the other performance are measures, the TWR and the SR determining the dimensional accuracy of a part, the MRR determining the economics of machining and the rate of production are the most importance. The Taguchi method is widely used in the engineering analysis, being a powerful tool to design with a good quality system. Moreover, This method employs special design of orthogonal array to investigate the effects of the machining parameters such as MRR,SR and TWR through a small number of experiments. Now a days, the Taguchi method was widely employed in several industries. The method to obtain the best machining parameter of the µ-EDM process. Prihandanaet al. [2] used Taguchi method to identify the best process parameters to increase the MRR of a dielectric fluid containing a micro-powder in the µ-EDM using the $L18$ orthogonal array. Tosun et al.[3] used Taguchi method to explore the effects of the Material removal rate and the kerf of the wire EDM. Their works revealed that Taguchi method was a most powerful approach used in designing an experiment fields. However, the Taguchi method can be used to optimize single performance characteristics. Hence, in order to optimize multiple performance characteristics, the researchers were found the grey relational analysis to be a suitable theory.

Somashekhar et al.[4] used a new approach for optimization of the µ-EDM process with multiple performance characteristics that would based on the statistical-based analysis of variance using ANOVA with the GRA. Chiang and Chang [5] applied the GRA to optimize the Wire EDM process with the multiple performance characteristics such as the MRR, TWR and the maximum SR.

Jung and Kwon [11] also used Taguchi method and GRA to find the best and suitable machining parameters to satisfy the various characteristics of the Electro discharge machining process. Shen et al. [12] determined the best combination of the process parameters during the electrical discharge machining process of 1Cr17Ni7 using Cu electrode based on the performance characteristics such as the MRR, the TWR and the SR. Muthu Kumar et al. [13] identified the best levels of the parameters with the GRA and percentage contribution of all parameters with the ANOVA to the optimization of parameters.

2. Experimental Procedure

Experiments were conducted on the CNC micro-electrical-discharge machine (die-sinking type) of a DT-110-model multi-process micro-machining tool. The working material use in this study was EN-24steel, widely used in the tool and die industry. EN-24 die steel is a very high-quality alloy steel. Silver tungsten (AgW) with the diameter of 300 μm was used as an electrode. EDM oil used as a dielectric in this experiment. A micro-electrical-discharge machine with an RC-type pulse generators were used to obtain a quality micro-hole in the EN-24 steel.

Experiments were conducted using the *L*16 orthogonal array, there parameters such as the gap voltage, the capacitance, the threshold and the feed rate were changes at 4 levels, with the level four being the higher value of the process variable. The machining parameters and their levels are high-lighted in **Table 1**.

Table 1: Machining parameters and their levels for micro-EDM

Parameters	*Level1*	*Level2*	*Level 3*	*Level 4*
Gap voltage (V)	80	100	120	140
Capacitance (nF)	0.1	1.0	10	100
Feed rate (μm/s)	2	4	6	8
Threshold (%)	20	40	60	80

The MRR (material removal rate) for the μ-EDM process can be measured by dividing the total volume of the material removed by the total machining time (T). Assuming a nil diametric wear of the electrode, the MRR is calculated on the basis of the effective hole depth, divided by the respective time. The effective depth of the hole is measured on the basis of the difference between the depth showing on the monitor of the machine calculation of the value of ANOVA with the use of the full factorial design (4^4) reduced the total of 256 sets of the experiments down to 16, thereby decreasing the time, effort and cost . Data pre-processing is a process of transferring the original sequence to a comparable sequence. Hence, the experimental results are normalized in the range between zero and one. Based on the characteristics of the data sequence, various methodologies are available for data pre-processing. [16] Therefore, a linear normalization of the experimental results for the MRR, the TWR and the surface roughness were performed.

3. Taguchi Technique

The Taguchi method is scientifically stream for implementing and evaluating improve in products, processes, materials, equipment, and facilities. This improvement are focused at improving the desired parameters and simultaneously decreasing the many number of faults by study the key variables control the machining and optimizing the procedures or design to very best results. This method is very useful over a large range of engineering fields that include processes those manufacturing raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, CAD, banking and service sectors etc. The Taguchi method is most useful for 'tuning' given process for 'effectively' results.

The general steps involved in the Taguchi technology are as follows:

1) To define the process objective, or more specifically, a target value for a performance measure of the process. The target of a process may also be a minimum or maximum. The deviation in the performance parameter from the target value is used to define the loss function for the process.
2) Determine the design characteristics affecting the process. characteristics are variables within the process that affect the performance calculate can be easily controlled.
3) To create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection process of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter.
4) Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5) To complete data analysis is determine the effect of the different parameters on the performance measure.

4. Design and Plan of the Experiments

To evaluate the effects on the machining parameters of the performance characteristics, a specially designed experimental procedure is needed. Classical process experimental-design methods are too difficult and too complex to use. Additionally, many number of experiments has to be carried out when the number of machining parameters increases.[14, 15] In this study, the Taguchi method, a powerful tool for the parameter design of performance characteristics, was used to determine the optimum process parameters for the maximum MRR, the minimum TWR and a lower surface roughness in the micro-EDM. Thus, the *S/N* ratio is considered to evaluate the effect of the machining parameters on the MRR, the TWR and the SR.

5. Results and Discussion

The plan of tests was developed within the aim of determining the various type of effects of the capacitance, the feed rate, gap voltage and the threshold. The such values calculated using all the equations which was generated and compared with the experimental measurements to find the optimum performance parameters. This study shows Taguchi method with the GRA can be normally used to determine optimum parameters in the micro-electrical discharge machining process with multiple characteristics. By using equations 1 and 2, the *S/N* ratio was calculated on the basis of the such experimental data. **Table 2** are listed in the experimental results.

Experiment 5 has best multiple characteristics among 16 experiments. In this study, the optimization of multiple performance characteristics of the μ-EDM of EN-24 die steel was converted into optimization of the GRG. The mean of GRG for each level of the parameters and also the total mean of GRG for 16 experiments are calculated and listed in **Table 4**. Usually, the larger is the GRG, the closer will product quality to the ideal value. Hence, a large GRG is desired for the suitable optimum performance. Therefore, the best and optimum parameters setting highlighted in **Table 4**, for a lower TWR, better MRR and SR is A2B1C4D3. The optimum level of such process parameters is the level with the highest GRG.

Table 2: Experimental chart for *L*16 orthogonal array and performance results

Exp. No	Level of parameter				Experimental result			*S/N* ratio (dB)		
	Gap voltage (V)	Capacitance (nF)	Feed rate (μm/s)	Threshold (%)	MRR (mm^3/s)	TWR(%)	SR (μm)	MRR	TWR	SR
1	80	0.1	2	20	0.00025	13.42	0.087	–72.03	–22.55	21.21
2	80	1	4	40	0.000555	14.01	0.098	–65.11	–22.93	20.18
3	80	10	6	60	0.000555	18.29	0.113	–65.11	–25.24	18.94
4	80	100	8	80	0.000527	16.70	0.107	–65.57	–24.45	19.41
5	100	0.1	4	60	0.001271	14.06	0.094	–57.92	–22.96	20.54
6	100	1	2	80	0.000533	17.03	0.101	–65.47	–24.62	19.91
7	100	10	8	20	8.86E–05	18.31	0.126	–81.05	–25.25	17.99
8	100	100	6	40	0.000478	14.16	0.117	–66.42	–23.02	18.64
9	120	0.1	6	80	9.22E–05	16.36	0.102	–80.70	–24.27	19.83
10	120	1	8	60	0.000939	16.12	0.116	–60.55	–24.15	18.71
11	120	10	2	40	0.000202	21.50	0.132	–73.89	–26.65	17.59
12	120	100	4	20	0.000894	13.22	0.136	–60.97	–22.42	17.33
13	140	0.1	8	40	0.001335	15.81	0.112	–57.49	–23.98	19.02
14	140	1	6	20	0.001249	13.49	0.139	–58.07	–22.60	17.14
15	140	10	4	80	9.87E–05	16.97	0.163	–80.11	–24.59	15.76
16	140	100	2	60	0.000516	17.85	0.161	–65.75	–25.03	15.86

Table 3: Experimental results using the grey relational analysis

Exp. No.	Normalized *S/N* ratio			Derivation sequence A_{oi}			Grey relational coefficient GC_{ij}			Grey relational
	MRR	TWR	SR	MRR	TWR	SR	MRR	TWR	SR	
1	0.3827	0.9697	1	0.6173	0.0303	0	0.4475	0.9429	1	0.7968
2	0.6765	0.8804	0.8104	0.3235	0.1196	0.1896	0.6071	0.8069	0.7250	0.7130
3	0.6765	0.3326	0.5835	0.3235	0.6674	0.4165	0.6071	0.4283	0.5456	0.527
4	0.6571	0.5199	0.6704	0.3429	0.4801	0.3296	0.5932	0.5101	0.6027	0.5687
5	0.9818	0.8736	0.8767	0.0182	0.1264	0.1233	0.9649	0.7982	0.8022	0.8551
6	0.6612	0.4792	0.7623	0.3388	0.5208	0.2377	0.5961	0.4898	0.6778	0.5879
7	0.0000	0.3302	0.4101	1.0000	0.6698	0.5899	0.3333	0.4274	0.4588	0.4065
8	0.6210	0.8595	0.5281	0.3790	0.1405	0.4719	0.5689	0.7806	0.5145	0.6213
9	0.0148	0.5620	0.7466	0.9852	0.4380	0.2534	0.3366	0.5331	0.6637	0.5111
10	0.8703	0.5923	0.5418	0.1297	0.4077	0.4582	0.7940	0.5508	0.5218	0.6222
11	0.3039	0.0000	0.3360	0.6961	1.0000	0.6640	0.4180	0.3333	0.4295	0.3936
12	0.8523	1.0000	0.2884	0.1477	0.0000	0.7116	0.7720	1.0000	0.4127	0.7282
13	1.0000	0.6325	0.5977	0.0000	0.3675	0.4023	1.0000	0.5764	0.5541	0.7102
14	0.9754	0.9591	0.2537	0.0246	0.0409	0.7463	0.9530	0.9245	0.4012	0.7596
15	0.0397	0.4863	0	0.9603	0.5137	1	0.3424	0.4933	0.3333	0.3897
16	0.6494	0.3822	0.0197	0.3506	0.6178	0.9803	0.5878	0.4473	0.3378	0.4576

Table 4: Response table for the grey relational grade (GRG)

	Grey relational grade					Rank (Max–Min)
Symbol	Parameter	Level 1	Level 2	Level 3	Level 4	
A	Gap voltage	0.6514	0.6177	0.5638	0.5793	4
B	Capacitance	0.7183	0.6707	0.4292	0.594	1
C	Feed rate	0.559	0.6715	0.6048	0.5769	3
D	Threshold	0.6728	0.6095	0.6155	0.5143	2

Total mean value of the GRG (μm) = 0.6030

5.1 Analysis of Variance (ANOVA)

ANOVA was used to investigate the parameters that significantly affect the characteristics. Therefore, ANOVA has done by analyzing the influence of the capacitance ,gap voltage, feed rate and threshold. The results of the analysis of variance (ANOVA) for the MRR, the TWR and the SR was calculated using the values of grey relational coefficients from **Table 3**.Shows that the various contribution of the threshold and capacitance, were 47.46 % and 39.36 %, respectively. Input parameters were found to be most significant parameters meaning that they are controlled the MRR and SR, TWR very effectively.

5.2 Confirmation Test

Confirmation test was carried out to predict and verify the development of the quality characteristics using the optimum combination. The given grey relational grade using the optimum level of such machining parameters.

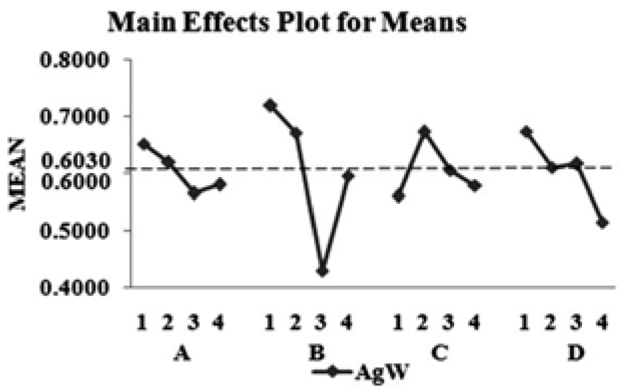

Figure 3: Main effects of the factors on the grey relational grade for AgW

Table 5: Micro-EDM results of *L*16 using the initial and optimum pro-cess factors

	Initial condition	Optimal factor	
		Prediction	Experiment
Level	A2B1C2D3	A1B1C2D1	A1B1C2D1
MRR	0.001272		0.00135
TWR	14.0578		13.4673
SR	0.095		0.0906
Grey relational grade	0.855	0.906	0.9348

Improvement of the grey relational grade: 0.0796

6. Conclusions

An orthogonal array with a GRA was used to optimize multiple response characteristics of the µ-EDM. Performance characteristics such as MRR, the electrode wear and the SR were improved using this method proposed in study.

According to the Taguchi L_{16} mixed orthogonal, only 16 experiments need to be conducted to find significant parameters. On the basis of integration of the GRA and the *S/N* ratio. Capacitance and the threshold are the main influencing parameters followed by the gap voltage and the feed rate. More precisely, significant parameters for whole machining performance were gap voltage of 80 V, the capacitance of 0.1 nF, the feed rate of 4 µm/s and the threshold of 20%. On the basis of the confirmation test, the improvement in performance was found to be as follows: MRR 3.96 %, TWR 4.45 % and SR 3.52 %.

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