Optimization Multi Response on Electrical Discharge Machining Sinking Process Using Taguchi-Grey-Fuzzy Methods

Rahayu Mekar Bisono[a], Rifky Maulana Yusron[b]

[a] Malang State Polytechnic (PSDKU) Kediri, Kediri, Indonesia

[b] Department of Mechanical Engineering University of Trunojoyo Madura, Bangkalan, Indonesia.

ABSTRACT

Electronic Discharge Machining (EDM) sinking applied widely in advance material manufacturing, every process parameter will count on this company. Their performance evaluated by some parameters such as surface roughness and tool wear ratio. Then they will be a dependent variable on this research. Independent variables on this research are electrode polarization, gap voltage, duty factor and pulse current. Every variable has three levels, except electrode polarization has two levels. This research conducting using Taguchi matrix orthogonal L18 (21×33) methods. The aim of this experiment is to evaluate optimization parameter process on EDM sinking, using Taguchi-Grey-Fuzzy methods. Characteristics response optimal applied are 'smaller better' for surface response roughness and tool wear ratio. This research using DAC tool steel as work-piece. DAC is most widely used as die for aluminum and zinc die-casting. The aim of this research is finding contribution of variable in EDM sinking parameter. Result of this research show contribution from variable process to reduce variance total observed response simultaneously, in order are electrode polarization on 49,53%, gap voltage on 23,52%, duty factor on 5,45% and pulse current on 9,92%. From validated optimization in confirmation experiment, to conclude combination variable process optimal response value is electrode polarization on positive, gap voltage at 50V, duty factor at 0.5 and pulse current at 12A.

Keywords: EDM sinking, electrode wear ratio, sourface roughness, Taguchi-grey-fuzzy.

1. Introduction

EDM is a thermoelectric machining process use to process conductive and semi conductive materials [1]. Electrical discharge machining (EDM) sinking is one of non-conventional machining process [2]. EDM sinking can process high hardness, ductile, heat resistance materials effectively [3]. This process can meet work-piece with complex geometry and tight tolerance requirement, who can't be achieve with other machining processes, such as the milling, drilling even shaping machine. EDM sinking is a metal cutting process by using erosion that occurs for several electric spark jumps. Electric spark jumps occur periodically in the gap between the cathode (work-piece) and the anode (tool) in dielectric, that's make EDM sinking have capability to processing work-pieces with complex contours [4]. Despite many technological advantages in shaping complex surfaces of hard materials, EDM sinking has several potential threats to both the direct surrounding of the workplace as well as to environment [5].

DAC tool steel is hot working tool steel with good balance of strength, toughness and heat resistance. This material has good machinability, by applied quenching treatment this material become tougher and increasing surface hardness [6]. This treatment make life cycle of dies became longer and stable. Applications of DAC material is dies for aluminum and zinc die-casting with low to medium pressure casting [7].

Tool wear ratio and surface roughness are two variable that very common to evaluate performance from EDM sinking [8]. Electrode wear ratio is a percentage ratio between volume of wasted electrodes and the volume of wasted material during machining [9]. Surface roughness is a characteristic of quality of final product [10].

2. Literature Review

2.1. Electrode wear ratio

Electrode wear ratio (EWR) is volume of electrode material who erosion and wasted during machining process [3]. The calculation of EWR using equation 1 [11]. On this research we measuring weigh of electrode before and after machining, using digital pocket scale with maximum capacity 200 gr and accuracy 0,01 g. Every parameter using different electrode include replication, it to make sure no contamination from previous machining.

* *Corresponding author.* Phone : +6285 732 098 732

E-mail address: rahayuyudhaputra@gmail.com

$$EWR = \frac{\Delta W_T}{\rho_t . t_m}$$ (1)

ΔW_T= electrode weight changing during machining (grams)

ρ_T = electrode density (gm/cm^3)

t_m = machining time (second)

2.2. Surface roughness

Surface roughness is surface anomaly due to conditions of machining process. In advance material manufacturing surface roughness have significant factor, due to friction, contact deformation, tightness of contact join, positional accuracy, tight tolerance heat and electric current conduction [12] [13]. Based on that statement we can conclude surface roughness is critical factor on EDM sinking [14]. On this research, surface roughness data obtaining by measurement on surface workpiece using mitutoyo surftest 301. Direction of measurement conducting diagonally on the surface workpiece.

2.3. S/N ratio

Taguchi method is a design of experiment approach for optimization of process parameters [15]. On this research they are electrode polarization, gap voltage, duty factor and pulse current. First step on optimization applied Taguchi-grey-fuzzy method is counting S/N ratio value for each response. Taguchi Method using S/N ratio approach to observe noise factor variables [16]. Response ratio of electrode wear and surface roughness has "smaller better" characteristics S / N ratio can be calculate with following equation.

$$S/N = -10 \, log \left[\sum_{i=1}^{n} \frac{y_i^2}{n} \right]$$ (2)

n = number of replication

y_i = characteristic values of observations.

Based on S / N ratio quality characteristics, value of a large S / N ratio shows good performance characteristics.

2.4. Data normalization

S / N ratio normalization process is changing the value of the S / N ratio to a value between 0 and 1. S / N ratio normalization process is changing the value of the S / N ratio to a value between 0 and 1 [17]. It also conducted based on response quality characteristics. Quality characteristic of S / N ratio is 'larger better'. Equation used in normalization process is as follows.

$$x_i^* k = \frac{x_i^* k - \min_{\forall k} x_i^* k}{\max_{\forall k} x_i^* k - \min_{\forall k} x_i^* k}$$ (3)

Where, max $\forall k$ Xi (k) is the largest value of Xi (k) for k-th, min$\forall k$ responseXi (k) is the smallest value of Xi (k) for k-th response

2.5. Deviation Sequence

Apart from absolute value and result of largest value normalization, it means difference between 1 and normalized data. Deviation sequence determined by following equation.

$$\Delta_{0,i}(k) = |X0(k) - Xi^*(k)|$$ (4)

2.6. Grey relational coefficient (GRC)

It shows correlation between ideal conditions (best) with actual conditions from normalized response. GRC will be declared 1 if normalized response matches with ideal conditions. Equation used to get that value.

$$\xi_i(k) = \frac{\Delta_{min} + \zeta \, \Delta_{max}}{\Delta_{0,i}(k) + \zeta \, \Delta_{max}}$$ (5)

Δmin is the smallest value of $\Delta_{0,i}$, Δmax is the largest value of $\Delta_{0,i}$ and ε is differentiating coefficient (common value is 0.5).

2.7. Fuzzification

Mapping methods use find a relationship between input variables and output variables based on fuzzy rules called fuzzy logic. The stages in fuzzy logic include fuzzification, followed by the applied fuzzy rules and defuzzification. Fuzzification is changing input variables that is GRC value from each response into a fuzzy number using membership function. Membership function used in this research is a triangular curve membership function as shown in Figure 1.
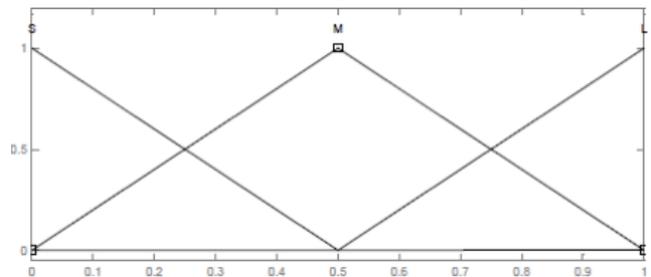

Figure 1. Membership function for electrode wear ratio and surface roughness

The membership classified into three fuzzy subsets classes, called small (S), medium (M) and large (L). Output variable of fuzzy logic system in this study is gray fuzzy reasoning grade (GFRG). The membership function used is the triangular curve membership function as shown in Figure 2. The GFRG membership function classified into five fuzzy cluster, called very small (VS), small (S), middle (M), larger middle (LM), larger (L).
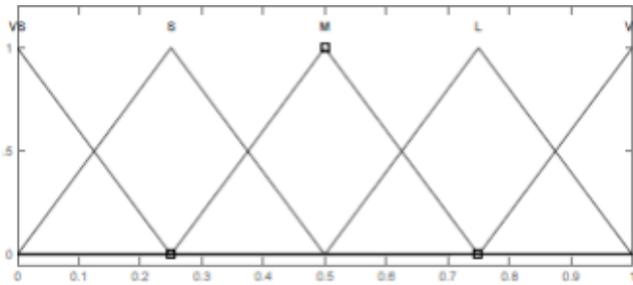
Figure 2. Membership function for output variable GFRG

2.8. ANAVA

Analysis of variance (ANAVA) is used to determine process variables that have a significant influence on responses and show how contribution of process variables to variable responses.

In this research, ANAVA conducted on GFRG. That mean a response representative from whole response. Statistically, the value of F_{cal} shows process variable decision has a major influence on the response. The value of F_{cal} and response variable are proportional. It means a contribution of response variable dependent on the value from F_{cal}. The contribution percentage shows portion (relative strength) of each process variable to total response, variance observed. If percent contribution error is less than fifteen percent, then no process variables have an denied effect but if percent of error contributions over fifteen percent show there are process variables that have denied effects.

3. Methods

This research using ZNC EDM Aristech LS-550 machine to process material and DAC Steel applied quenching treatment as material. Material wide 25mm, height 15mm and depth 5 mm. We using graphite as electrode and the dimension are wide 15mm, height 15mm and depth 5 mm. Previous research discuss about effect on electrode polarity to fatigue life tool in EDM sinking using high manganese steel workpiece and graphite electrode, was conclude EDM sinking using graphite electrode result material's surface roughness has an effect on increasing the fatigue life [18]. Another research using tool steel specimen using zinc coated electrode wire EDM. This research conclude results smaller wire can make better surface roughness [19].

On this research, we apply design experiment four independent variables will be varieties. They are electrode polarization, gap voltage, duty factor and pulse current. Design experiment using matrix orthogonal L_{18} (21x33) shown in Table 1.

Table 1. Design experiment matrix orthogonal L_{18} (2^1x3^3)

Combination	Variable			
	Electrode polarization	Gap voltage	Duty factor	Pulse current
1	Negative	30 V	0,3	6 A
2	Negative	30 V	0,5	9 A

Combination	Variable			
	Electrode polarization	Gap voltage	Duty factor	Pulse current
3	Negative	30 V	0,7	12 A
4	Negative	40 V	0,3	6 A
5	Negative	40 V	0,5	9 A
6	Negative	40 V	0,7	12 A
7	Negative	50 V	0,3	9 A
8	Negative	50 V	0,5	12 A
9	Negative	50 V	0,7	6 A
10	Positive	30 V	0,3	12 A
11	Positive	30 V	0,5	6 A
12	Positive	30 V	0,7	9 A
13	Positive	40 V	0,3	9 A
14	Positive	40 V	0,5	12 A
15	Positive	40 V	0,7	6 A
16	Positive	50 V	0,3	12 A
17	Positive	50 V	0,5	6 A
18	Positive	50 V	0,7	9 A

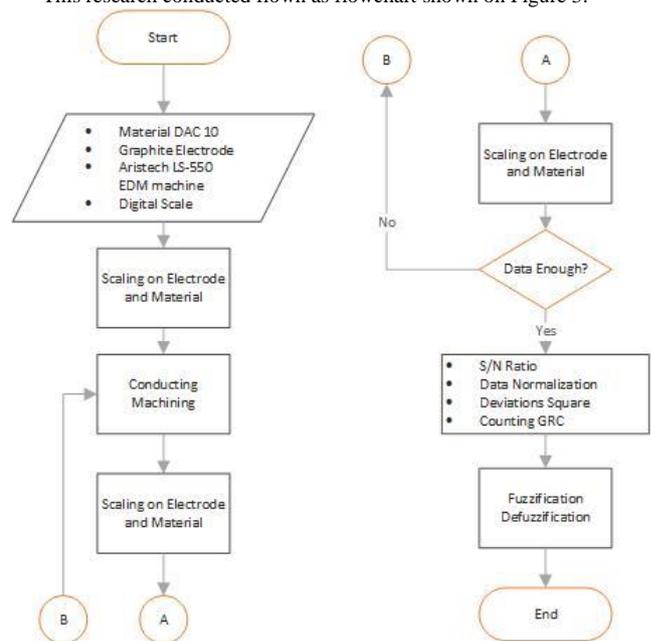This research conducted flown as flowchart shown on Figure 3.

Figure 3. Research Flowchart

4. Result

Based on experiment result we have electrode wear ratio (EWR) and surface roughness value ordered by design experiment matrix orthogonal L18 shown on table 2

Table 2. Experiment Data

Combination	Electrode Wear Ratio (μg)		Surface Roughness (μm)	
	R1	R2	R1	R2
1	2.84	2.60	9.00	8.56
2	2.68	2.57	10.10	10.34
3	2.67	2.65	12.12	12.36
4	2.84	2.85	9.57	9.12
5	2.68	2.52	10.82	10.64
6	2.62	2.60	12.25	12.33
7	2.68	2.55	9.44	9.52
8	2.47	2.48	11.04	11.04
9	2.63	2.55	8.90	9.14
10	2.45	2.47	8.62	8.85
11	2.54	2.50	6.50	6.71
12	2.47	2.52	8.20	7.95
13	2.57	2.54	7.08	7.25
14	2.39	2.42	8.66	8.53
15	2.62	2.67	8.67	9.12
16	2.40	2.36	8.08	8.26
17	2.42	2.40	6.13	6.32
18	2.42	2.38	7.87	8.09

Table 3. Experiment Data

Combi nation	S/N Ratio		GRC		GFRG
	EWR	SR	EWR	SR	
1	-8.706	-18.871	0.399	0.497	0.4391
2	-8.389	-20.191	0.4757	0.4068	0.4813
3	-8.491	-21.756	0.4479	0.3347	0.4586
4	-9.093	-19.413	0.3333	0.4555	0.4071
5	-8.316	-20.610	0.4978	0.3846	0.4982
6	-8.328	-21.791	0.4939	0.3333	0.4947
7	-8.352	-19.535	0.4866	0.4472	0.4897
8	-7.868	-20.93	0.6958	0.3688	0.6031
9	-8.280	-19.105	0.5092	0.4783	0.5067
10	-7.818	-18.828	0.7281	0.5007	0.6162
11	-8.028	-16.399	0.6089	0.8511	0.5773
12	-7.945	-18.146	0.6513	0.5662	0.5881
13	-8.148	-17.103	0.5572	0.7075	0.5480
14	-7.631	-18.685	0.8803	0.5131	0.6804
15	-8.437	-18.987	0.4621	0.4875	0.4737
16	-7.525	-18.247	1.0000	0.5554	0.752
17	-7.637	-15.881	0.8753	1.0000	0.7184
18	-7.622	-18.043	0.8901	0.5776	0.688

Table 3 shows results of data processing to get the GFRG value. After getting GFRG value, next step is getting ANAVA. Table 4 shown result of ANAVA.

Table 4. ANAVA GFRG

Variable process	DF	SS	MS	F	P$_{value}$	Contribution
electrode polarization	1	0.08882	0.08882	73.72	0.000	49.53%
gap voltage	2	0.04401	0.02201	18.27	0.000	23.52%
duty factor	2	0.01205	0.0060	5.00	0.031	5.45%
pulse current	2	0.01996	0.00998	8.29	0.008	9.92%
error	10	0.01205	0.00120			11.58%
total	17	0.17690				100%

Table 4. show all process variables Fcal value larger than Ftable. It can be conclude that statistically the polarity process variable electrode, gap voltage, duty factor and pulse current has significant influence from response observed electrode wear ratios and surface roughness simultaneously.

Determination of level combination of both process variables make optimum response can be determine base on largest average GFRG value. Optimum level from process variables are electrode polarity at level 2 (positive), gap voltage at level 3 (50 V), duty factor at level 2 (0.5) and pulse current at level 3 (12 A). Table 5 shown the results of calculation from average GFRG.

Table 5. Design experiment matrix orthogonal L$_{18}$ (2^1x3^3)

Variable process	Level 1	Level 2	Level 3	Difference
electrode polarization	0.4865	0.6270	-	0.1405
gap voltage	0.5286	0.5170	0.6265	0.1094
duty factor	0.5420	0.5931	0.5351	0.0580
pulse current	0.5240	0.5490	0.6009	0.0805
total average		0.5567		

Table 6 shows the comparison of the results of the EDM sinking machining process under the initial conditions and at the optimum conditions. Based on Table 6, GFRG value at initial condition is 0.7028 and GFRG value at optimum condition is 0.7994. That showed the value of GFRG has increased by 13.75%.

Table 6. Result of confirmation experiment

Response	Initial Combination ($A_1B_2C_2D_2$)	Optimum Combination	
		Forecast ($A_2B_3C_2D_3$)	Confirmation ($A_2B_3C_2D_3$)
Electrode wear ratio (EWR)	2.39		1.71
Surface roughness (SR)	10.77		6.75
S/N Ratio EWR	-7.586		-4.643
S/N Ratio SR	-20.644		-16.586
GRG	0.7028	0.7772 ± 0.0364	0.7994
Increasing GRG		13.79%	
S/N Ratio EWR Increasing		38.79%	
S/N Ratio SR Increasing		19.66%	

Smaller better characteristic from response electrode wear ratio and surface roughness completed. This showed by an increasing value of the S / N ratio from each response. Increasing of S / N ratio in electrode wear ratio was 38.79% and the response of surface roughness was 19.66%.

5. Conclusion

This paper has given an overview about process variable on EDM Sinking, from the experiment we can conclude process variables have contribution on total variance from electrode wear ratio and surface roughness simultaneously were electrode polarity of 49.53%, gap voltage of 23.52%, pulse current of 9.92% and duty factor of 5.45%. Optimum combination settings that can produce a minimum response are electrode polarity set positive, the gap voltage at 50 V, the duty factor at 0.5 and the pulse current at 12 A. This research no comparable with previous research. A research conducted on 316L Stainless steel and copper carbide electrode has conclude that variable has significant effect are pulse on time, servo voltage and servo speed [12] this research using metal electrode, beside we using non-metal metal electrode and research observe process variable on micro EDM that open voltage and capacitor have the most effect on surface roughness because these two parameters are the main influence factors of discharge energy [14], this research using micro EDM and we using different parameter process. Although due on limitation of ZNC EDM Aristech LS-550 parameter process comparing on previous research. Summing up from the result above this research might helpful operator with similar machine to optimization on EDM sinking process.

REFERENCES

[1] A. K. Singh, R. Mahajan, A. Tiwari, D. Kumar, and R. K. Ghadai, 'Effect of Dielectric on Electrical Discharge Machining: A Review', *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 377, no. 1, 2018, doi: 10.1088/1757-899X/377/1/012184.

[2] K. . Ho and S. . Newman, 'State of the art electrical discharge machining (EDM)', *Int. J. Mach. Tools Manuf.*, vol. 43, no. 13, pp. 1287–1300, Oct. 2003, doi: 10.1016/S0890-6955(03)00162-7.

[3] V. S. Jatti, 'Multi-characteristics optimization in EDM of NiTi alloy, NiCu alloy and BeCu alloy using Taguchi's approach and utility concept', *Alexandria Eng. J.*, vol. 57, no. 4, pp. 2807–2817, 2018, doi: 10.1016/j.aej.2017.11.004.

[4] M. Zhou, J. Wu, X. Xu, X. Mu, and Y. Dou, 'Significant improvements of electrical discharge machining performance by step-by-step updated adaptive control laws', *Mech. Syst. Signal Process.*, vol. 101, pp. 480–497, 2018, doi: 10.1016/j.ymssp.2017.06.041.

[5] T. Leppert, 'A review on ecological and health impacts of electro discharge machining (EDM)', *AIP Conf. Proc.*, vol. 2017, no. October, 2018, doi: 10.1063/1.5056277.

[6] D. N. Passarella, F. Varas, and E. B. Martín, 'Heat transfer model for quenching by submerging', *J. Phys. Conf. Ser.*, vol. 296, no. 1, 2011, doi: 10.1088/1742-6596/296/1/012004.

[7] S. Oh and H. Ki, 'Deep learning model for predicting hardness distribution in laser heat treatment of AISI H13 tool steel', *Appl. Therm. Eng.*, vol. 153, pp. 583–595, May 2019, doi: 10.1016/J.APPLTHERMALENG.2019.01.050.

[8] T. Vijaya Babu and J. S. Soni, 'Investigation of process parameters optimization in die-sinking and wire cut EDM to improve process performance using taguchi technique', *Mater. Today Proc.*, vol. 5, no. 13, pp. 27088–27093, Jan. 2018, doi: 10.1016/J.MATPR.2018.09.014.

[9] K. Wang, Q. Zhang, G. Zhu, Y. Huang, and J. Zhang, 'Influence of tool size on machining characteristics of micro-EDM', *Procedia CIRP*, vol. 68, no. April, pp. 604–609, 2018, doi: 10.1016/j.procir.2017.12.122.

[10] H. Huang, M. Li, G. Chi, and Z. Wang, 'Development of the adjusting and inspecting equipment for EDM', no. Nceece, pp. 715–721, 2016, doi: 10.2991/nceece-15.2016.133.

[11] H. P. Nguyen and V. D. Pham, 'Single objective optimization of die- sinking electrical discharge machining with low frequency vibration assigned on workpiece by taguchi method', *J. King Saud Univ. - Eng. Sci.*, no. xxxx, pp. 1–6, 2019, doi: 10.1016/j.jksues.2019.11.001.

[12] A. M. Deris, A. M. Zain, R. Sallehuddin, and S. Sharif, 'Harmony search optimization in dimensional accuracy of die sinking EDM process using SS316L stainless steel', *J. Phys. Conf. Ser.*, vol. 892, no. 1, 2017, doi: 10.1088/1742-6596/892/1/012003.

[13] E. S. Gadelmawla, M. M. Koura, T. M. A. Maksoud, I. M. Elewa, and H. H. Soliman, 'Roughness parameters', *J. Mater. Process. Technol.*, vol. 123, no. 1, pp. 133–145, 2002, doi: 10.1016/S0924-0136(02)00060-2.

[14] X. Fu, L. Gao, Q. Zhang, and Q. Liu, 'Surface Roughness Research of Piezoelectric Self-adaptive Micro-EDM', *Procedia CIRP*, vol. 42, no. Isem Xviii, pp. 563–568, 2016, doi: 10.1016/j.procir.2016.02.252.

[15] R. A. Anugraha, M. Y. Wiraditya, M. Iqbal, and N. M. Darmawan, 'Application of Taguchi Method for Optimization of Parameter in Improving Soybean Cracking Process on Dry Process of tempeh Production', *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 528, no. 1, 2019, doi: 10.1088/1757-899X/528/1/012070.

[16] S. Winarni and S. W. Indratno, 'Application of multi response optimization with grey relational analysis and fuzzy logic method', *J. Phys. Conf. Ser.*, vol. 948, no. 1, 2018, doi: 10.1088/1742-6596/948/1/012075.

[17] A. K. Rouniyar and P. Shandilya, 'Multi-Objective Optimization using Taguchi and Grey Relational Analysis on Machining of Ti-6Al-4V Alloy by Powder Mixed EDM Process', *Mater. Today Proc.*, vol. 5, no. 11, pp. 23779–23788, 2018, doi: 10.1016/j.matpr.2018.10.169.

[18] H. B. Özerkan, 'Effect of electrode polarity on fatigue life in EDM', *MATEC Web Conf.*, vol. 224, 2018, doi: 10.1051/matecconf/201822401107.

[19] H. Hanizam, N. Mohamad, U. A. A. Azlan, and M. Qamaruddin, 'Process Optimization of EDM Cutting Process on Tool Steel using Zinc Coated Electrode', *MATEC Web Conf.*, vol. 97, pp. 0–4, 2017, doi: 10.1051/matecconf/20179701073.