Multi-Objective Optimization of Process Parameter in EDM Using Low-Frequency Vibration of Workpiece Assigned by PSI

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***Abstract*— This report addresses multi-objective optimization in EDM for SKD61 die steel using low-frequency vibration. PSI (Preferential Selection Index) was chosen to resolve this multi-objective optimization problem. The material removal rate (MRR) and tool wear rate (TWR) were selected as performance measures in the EDM process. The results indicate that the optimum parameters required to achieve the multi-objective were Ton = 12 µs, I = 6 A, Tof = 12.5 µs, and F = 512 Hz, at the resultant quality criteria of MRR = 4.46 mm3/min and TWR = 0.024 mm3/min.**

***Index Terms*— Material removal rate, Tool wear rate; Low frequency vibrational; PSI**

I. INTRODUCTION

The EDM process has been frequently used to form dies, tool surfaces and in aerospace technology. The application of low-frequency vibration in EDM can be used to significantly increased machining efficiency. This often results in the shortest distance between tools and workpieces. The approach also enhances the flushing effect and creates better dielectric circulation between the electrode and the workpiece. Integrated vibrations in EDM have been achieved by integrating electrodes or workpieces. The low-frequency vibrations are assigned to electrical arc machining for W9Mo2Cr4V (Zhu et al., 2018). The results indicate that integrated vibration in the machining process increases MRR by reducing the tool wear and surface roughness. Similar results have been reported for EDM of Inconel-718 via the application of low-frequency vibrations (F = 0–80 Hz) (Unune and Mali, 2016). The results indicated that the increased vibration frequency causes an increase in the MRR by 27.6%, electrical wear rate (EWR) by 6.16%, in addition to a reduction of overcut and taper angle by 31.84% and 18.58%, respectively. The increasing performance measure is associated with the improvement in the flow of chips at various vibrations of electrodes or workpieces in EDM drilling (Unune et al., 2019). The assignment of vibrations to µ-EDM results in higher efficiency. The low-frequency vibration (F = 10–70 Hz) is assigned to the workpiece in µ-EDM drilling, which significantly improves the flushing efficiency of the dielectric fluid flow in addition to enhancement of the stability of the machining process. This contributes to a 70% reduction in the machining time relative to conventional EDM (Pyeong et al., 2015). Compared to conventional WEDM, WEDM with low-frequency vibration (F = 0–80 Hz) assigned to an Inconel 718 workpiece demonstrated that MRR is improved by 66.20% and the adhesion of the chip to the machined surface is significantly reduced (Deepak and Harlal, 2017). Ultrasonic vibrations assigned to the electrodes in EDM have revealed the efficient release of chips (Liu et al., 2017). Moreover, vibrations with an ultrasonic frequency of 5 kHz have resulted in an MRR that is six times higher compared to µ-EDM assigned to workpieces in the case of scanning 3D µ-EDM (Hao and Yang, 2008). In EDM with a vibration frequency F = 40 kHz, the MRR and TWR were increased by 47% and 18%, respectively (Puthumana et al., 2016).

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II. EXPERIMENTAL SETUP

Through conducting the EDM, experiments involve current (I), voltage (U), pulse on-time (Ton), pulse off-time (Tof). SKD61 die steel has been used as workpiece material having dimensions of 25x25x30 mm (Figure 1). Copper (Cu) electrode material was used in the EDM process. The dielectric fluid of the experiment is D323 oil (Vietnam). The CNC- CM323C die-Sinking machining (CHMER, Taiwan) has been used to experiment. Mass of a workpiece is measured before and after machining with AJ 203 electronic balance (Shinko Denshi Co. LTD - Japan) with a maximum weight of 200g, an accuracy of 0.001g. The workpiece was attached to the vibration protection fixture of the vibration unit to facilitate stable and accurate transmission of vibrations to the workpiece. Trial runs were performed to evaluate the stability of the system. The vibration unit (Modal: Exciter 4824, Brüel & Kjær, Denmark) was used to investigate the vibrations.

Table 1. Experimental matrix and observed EDM performance measures

No EX.	I (A)	Ton (µs)	Tof (µs)	F (Hz)	MRR (mm^3/min)	TWR (mm^3/min)
	3	12	5.5	128	2.333	1.544
	3	25	12.5	256	2.827	0.122
	3	50	25	512	3.564	0.124
	6	12	12.5	512	4.460	0.024
	6	25	25	128	3.154	2.048
	6	50	5.5	256	5.470	0.757
	8	12	25	256	5.855	1.011
	8	25	5.5	512	9.564	1.944
	8	50	12.5	128	5.205	0.079

III. Results and Discussion

Step 1: The PSI method was used to simultaneously optimize the three quality criterion: MRR and TWR, Table 1 .

Step 2: **The selected criteria are sorted in a matrix form:**

$$x = \begin{bmatrix} MRR_1 & TWR_1 \\ - & - \\ - & - \\ - & - \\ MRR_9 & TWR_9 \end{bmatrix}$$

Step 3: Using equation , and shown in **Table 2**.

Table 2. Transformation matrix of quality criteria

Exp. No	I (A)	Ton (µs)	Tof (µs)	F (Hz)	MRR (mm^3/min)	TWR (mm^3/min)	X^*	
							MRR	TWR
1	3	12	5.5	128	2.333	1.544	0.2439	0.0155
2	3	25	12.5	256	2.827	0.122	0.2956	0.1967
3	3	50	25	512	3.564	0.124	0.3726	0.1935
4	6	12	12.5	512	4.460	0.024	0.4663	1.0000
5	6	25	25	128	3.154	2.048	0.3298	0.0117
6	6	50	5.5	256	5.470	0.757	0.5719	0.0317
7	8	12	25	256	5.855	1.011	0.6122	0.0237
8	8	25	5.5	512	9.564	1.944	1.0000	0.0123
9	8	50	12.5	128	5.205	0.079	0.5442	0.3038

Step 4 to step 8: The standardized criteria are calculated and shown in **Table 3**.

Table 3. Normalization matrix of criteria with weights

Exp. No	N	Φ		¯j	¯j	Wj	θj
		MRR	TWR				
1	0.130	0.114	-0.114	0.026	0.974	0.123	0.032
2	0.246	0.049	-0.049	0.005	0.995	0.126	0.062
3	0.283	0.090	-0.090	0.016	0.984	0.124	0.070
4	**0.733**	**-0.267**	**0.267**	**0.142**	**0.858**	**0.108**	**0.159**
5	0.171	0.159	-0.159	0.051	0.949	0.120	0.041
6	0.302	0.270	-0.270	0.146	0.854	0.108	0.065
7	0.318	0.294	-0.294	0.173	0.827	0.104	0.066
8	0.506	0.494	-0.494	0.488	0.512	0.065	0.065
9	0.424	0.120	-0.120	0.029	0.971	0.123	0.104

Step 9: Ranked index by the PSI method: Table 3 indicates that the 4^{th} experiment has the highest θj value among all the quality criterion. Therefore, the 8^{th} experiment provides the optimal process parameters: Ton = 12 µs, I = 6 A, Tof = 12.5 µs, and F = 512 Hz. The corresponding optimal process parameters and the quality criteria such as MRR = 4.46 mm^3/min and TWR = 0.024 mm^3/min.

Conclusions

The results of an investigation on the optimization of multi-objective in EDM using low-frequency vibration on the workpiece SKD61 using PSI method have shown that a low vibration frequency significantly improves the removal productivity of the material. The optimal process parameters are Ton = 12 µs, I = 6 A, Tof = 12.5 µs, and F = 512 Hz and the associated quality indicators are MRR = 4.46 mm^3/min and TWR = 0.024 mm^3/min.

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