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MCDM Optimization of Machining EDM Helical Hole Trajectory Using Hybrid TOPSIS - GRA Approach

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A B S T R A C T

In Electric Discharge Machining (EDM), the optimization of parameters plays a crucial role in the production of helical trajectory holes with exceptional mechanical properties. In the present study, a manufacturing experiments were conducted on EDM machine to create holes with a helical path. A specialized mechanism was developed to facilitate the production of these holes with the desired helical trajectory. Primary quality criteria for the targeted EDM process were high metal removal rates (MRR), low electrode tool wear (TWR), and low surface roughness (Ra). Given the presence of three response variables and three objectives, a multiple-criteria decision-making approaches MCDM: TOPSIS, GRA, and hybrid GRA-TOPSIS methods were applied to investigate the optimal EDM parameters, namely current intensity (I), pulse on time (Ton), and pulse-off time (Toff). These MCDM methods led to converge on the optimal parameters, which were determined as 30 A for current intensity (I), 45 μs for pulse on time (Ton), and 5 μs for pulse-off time (Toff). This study's findings suggest that the optimal parameters remained consistent regardless of the statistical techniques applied to analyze the experimental data.

1. Introduction

Electro-discharge machining (EDM) is widely adopted non-conventional machining process known for its effectiveness. This electrical-thermal process relies on the generation of sparks to remove material. These sparks vaporize a small portion of the target material, making EDM advantageous, as it remains unaffected by the hardness or strength of the workpiece.

In conventional manufacturing, 'drilling' typically refers to the creation of straight holes. Many mechanical engineers have traditionally assumed that machining curved or helical trajectory holes is not practical. However, certain applications require holes with curved or helical shapes (as shown in Fig. 1), necessitating designers to modify the part's geometry to accommodate traditional machining methods.

Some prior studies have delved into the creation of curved holes through the use of Electrical Discharge Machining EDM [1][2][3], with a few even exploring the fabrication of L-shaped curved holes [4]. However, there remains a gap in the literature concerning the constructive elements and the tool electrode's

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geometry necessary for inducing electrical erosion to produce helical trajectory holes. Numerous research efforts have been devoted to optimizing EDM parameters, and it has been observed that the Grey Relational Analysis (GRA) methodology yields superior results in this regard [5]. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has also found applicability in optimizing EDM parameters, particularly for steel materials, demonstrating satisfactory outcomes [6]. In a bid to further enhance the optimization process, a hybrid approach combining GRA and TOPSIS has shown promise [7].

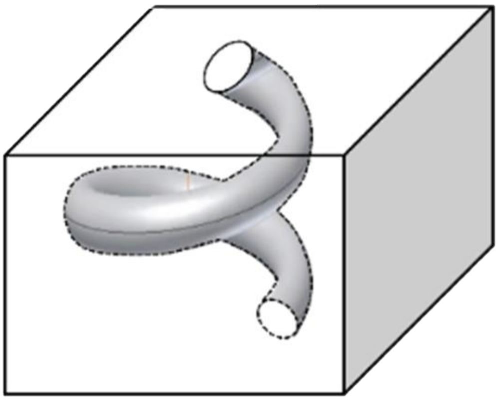


Fig. 1 Demonstration for helical hole trajectory

To address this challenge, there is a need to establish a fabrication method for creating helical trajectory holes. In the present work, a specialized mechanism has been developed as shown in Fig. 2 to facilitate the fabrication of holes with the desired helical path. Optimal EDM parameters were investigated using the TOPSIS, GRA, and hybrid GRA-TOPSIS statistical approaches, aiming to achieve a high metal removal rate, low electrode tool wear, and low surface roughness.

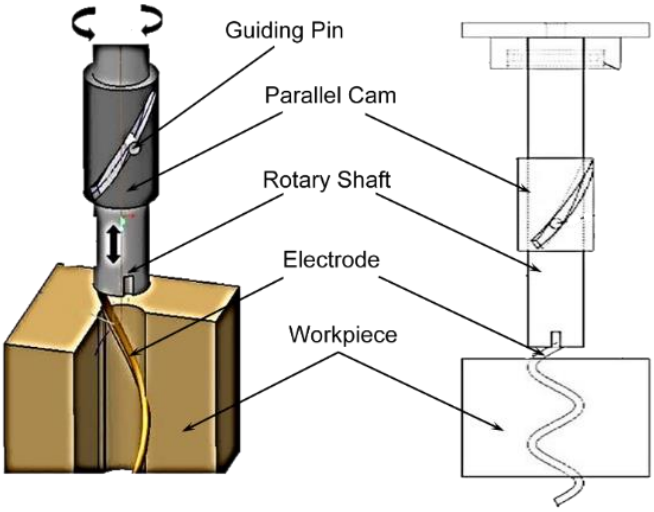


Fig. 2 Demonstration of the designed mechanism

2. Experimental Work

With the intention of producing hole with helical path, it was necessary to develop a special mechanical mechanism. This mechanism is important to convert the conventional linear motion of the machine head into the desired helical motion with certain pitch. Fig. 2 demonstrates the designed mechanism used in this research. The helical copper electrode is produced by bending process using a helical grooved mandrel. Electrode has dimensions of 20 mm diameter, 150 mm length, with depth of 2.5 mm, and diameter of 7 mm, and 50 mm pitch. Fig. 3 shows the mechanism on EDM machine.

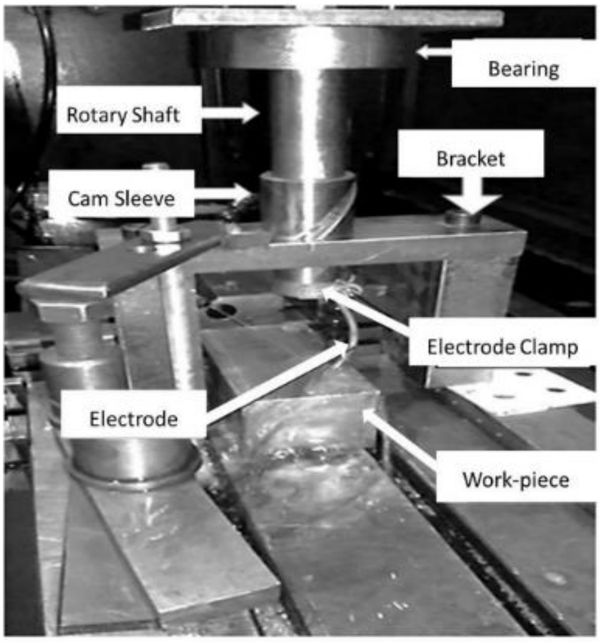


Fig. 3 Helical hole mechanism on EDM operation

Experimental trials were conducted to decide the effective range of variables following a design matrix consists of 25 experiments randomly chosen from full factorial orthogonal matrix in order to minimize the experimental cost, in addition, during machining, the experiments were chosen in a random order to avoid any systematic error. In order to have results that can present an impact on EDM cutting industry, factors levels were chosen around the recommended cutting variables provided by the machine manufacturer to get better surface quality. Factors, factor levels and factor designations are shown Table 1. Table 2 illustrate the non-variable parameter during cutting.

Table 1 Factor levels, designation, and values

Factor	**Unit**	**Levels and values**				
		1	**2**	**3**	**4**	**5**
Current, (I)	Ampere	10	12	15	20	30
T_{on}	µs	45	80	120	150	200
T_{off}	µs	1	2	3	4	5

Table 2 Non-variable EDM process parameter

Parameter	**value**
Die electric fluid	Kerosene
Flow rate ($Cm^3\ s^{-1}$)	3
Polarity	Positive for electrode
Duty factor (%)	79
Gap (mm)	0.07
Spark holding time (sec)	5

A bar of aluminum with standard grade Al-Si-Mg alloy AA 6060 was chosen as workpiece material in this research. PNC-75A EDM sinking machine were used to perform the cut as shown in Fig. 4.

Fig. 4 EDM machine PNC 75A

Tool wear rate (TWR) was calculated by weighing the electrode before and after the machining process using precision 1-mg precision scale. The formula which is used for electrode wear determination is as follows:

$$TWR = \frac{(m_1 - m_2)_{electrode}}{\rho \times Time} \quad (1)$$

To calculate the material removal rate (MRR), the workpieces weights were measured before and after machining the helical hole. The formula used in this calculation is as follows:

$$MRR = \frac{(m_1 - m_2)_{workpiece}}{\rho \times Time} \quad (2)$$

The average surface roughness parameter (Ra) values were measured according to iso standard using TR200 roughness tester. Three measurements were performed for each specimen, and an average value was calculated for each specimen. Fig. demonstrates the TR200 surface roughness tester used in this research.

Fig. 5 TR200 Surface roughness tester

Table 3 Taguchi L_{25} orthogonal array experimental trials and responses

Exp. No.	Controllable process parameters			Process responses		
	I (A)	T_{on} (μs)	T_{off} (μs)	TWR (mm^3/min)	MRR (mm^3/min)	Ra (μm)
1	10	45	1	0.000306	0.02	5.2
2	10	80	2	0.000245	0.0429	5.85
3	10	120	3	0.000165	0.0631	6.5
4	10	150	4	0.000154	0.0821	7.8
5	10	200	5	0.000061	0.0848	8.3
6	12	45	2	0.00132	0.0469	5.8
7	12	80	3	0.00132	0.0867	6.8
8	12	120	4	0.000909	0.1	7.8
9	12	150	5	0.0008	0.127	9
10	12	200	1	0.000004	0.135	11.5
11	15	45	3	0.00535	0.053	6.6
12	15	80	4	0.0034	0.0931	7.65
13	15	120	5	0.00268	0.116	8.8
14	15	150	1	0.0019	0.133	10.5
15	15	200	2	0.00156	0.142	12.5
16	20	45	4	0.0128	0.0809	7.5
17	20	80	5	0.0106	0.122	8.56
18	20	120	1	0.00652	0.133	9.8
19	20	150	2	0.0042	0.136	11.5
20	20	200	3	0.0025	0.15	12.5
21	30	45	5	0.0188	0.0957	7.8
22	30	80	1	0.0133	0.131	10.5
23	30	120	2	0.00667	0.145	11.57
24	30	150	3	0.00455	0.149	12.7
25	30	200	4	0.00291	0.162	14.2

3. MCDM Analysis

Acquiring the optimal process parameters assumes an essential part in accomplishing the most appropriate response values which satisfying prerequisites of both the producers and end clients. The use of any of the MCDM procedures principally targets the identification of best alternate from a group of arrangements in presence of multi-conflicting criteria [8]. Among them comes the GRA and TOPSIS and the hybrid technique between them.

3.1. Grey Relational Analysis (GRA) Method

This technique was started by Julong Deng early in 1982 [9]. It is a statistical approach which converts a multi-response to a single objective [10]. In GRA method, all responses values are normalized the range of zero and one. These normalized values are implemented in calculating the response's GRA coefficient for each response. After that the gray relational grade (GRG) is processed for each trial run by averaging the gray relational coefficient. Solution with more prominent GRG gives ideal solution characteristics.

3.2. TOPSIS Analysis Method

TOPSIS is a MCDM technique developed by Hwang and Yoon that gives a method for getting optimum solution from numerous alternative ones [11]. This optimum solution is the most nearby to the ideal positive solution and the more far away from the ideal negative one. The objective is to evaluate the 25 trials, and the attributes are MRR, TWR and Ra. For this specific issue, MRR is considered as the most interest trait (i.e., higher values); while TWR and Ra could be less of interest (i.e., smaller values).

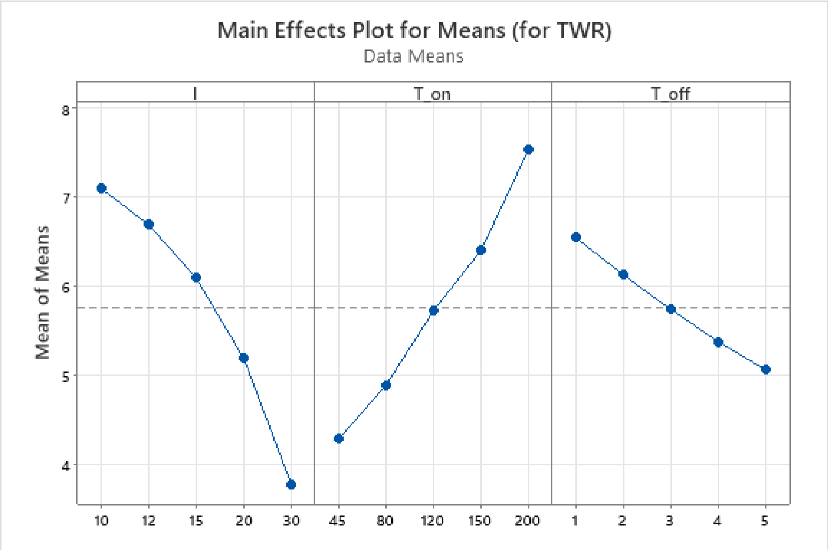
3.3. Hybrid GRA-TOPSIS

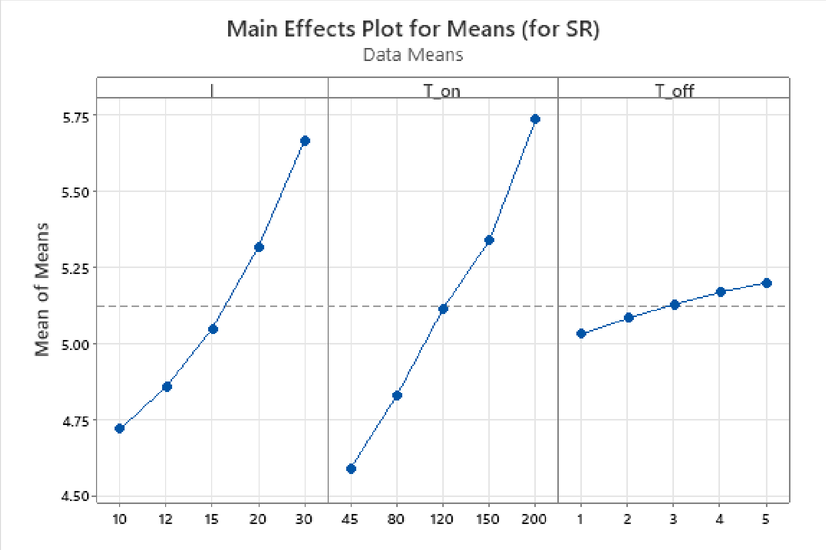
GRA-TOPSIS considered as a hybrid MCDM method for solving complex multi-response optimization problems. Typical TOPSIS technique has some limitations such as ranking reversal [12] and the failure to deal with relative significance of the separation from the two reference focuses [13]. Limitations of TOPSIS can be handled to by implementing grey relational coefficient of GRA as a substitution to the meaning of geometric distance [14]. Hybrid GRA-TOPSIS technique varies from the ordinary TOPSIS in the use of grey relational coefficient rather than geometric distance.

4. Results and Discussion

4.1. Effect of EDM Process Parameters

As the objective of this study to improve the EDM process responses. Hence, it is important to achieve maximum MRR with minimum TWR and Ra values. Fig. shows main effect plots for the process input parameters (I, T_{on}, T_{off}) on the responses of (TWR, Ra, MRR). It is obvious that TWR is decreased with current (I) from 10A to 30A. Meanwhile TWR is increased in the range from 45 μs to 200 μs which implies that nominal value for T_{on} is important for lower tool wear. T_{off} has slight impact in TWR in the tested range from 1 μs to 5 μs. As the decrease in T_{off} values results in lower wear of the electrode. Surface roughness in significantly influenced by increasing the values of input parameters (I, T_{on}, T_{off}). As reducing the EDM parameters led to enhance the Ra of machined surface. Also, the process parameters affect the MRR were investigated. Clearly pulse duration has the most part impacted on MRR. Maximum removal rate is achieved at high current of 30A and Ton of 200 μs. This can be made sense of based on expansion in the energy discharge rate, as high centralization of energy in the spark gap prompts fast melting and evaporation of target workpiece, as in return prompts ascends in the MRR. Subsequently, higher frequencies of discharge result in higher material removal rate.





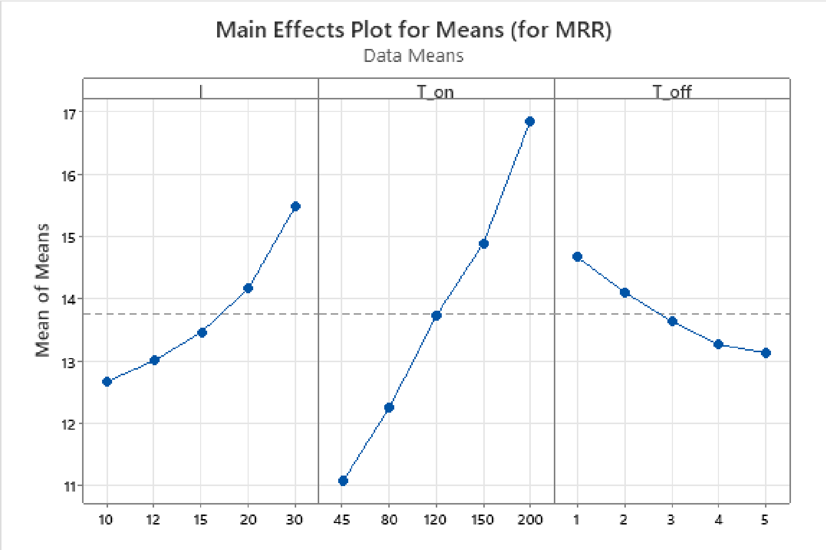


Fig. 6 Main effect of current, T_{on} and T_{off} on EDM process responses

4.2. GRA Analysis Results

Table 4 shows the normalized value of the trials. GRG was calculated considering the average of grey coefficient obtained for TWR, MRR, and Ra. The ranking was designated based on the GRG. For this instance, the most higher GRG was found to be 0.63974 and henceforward allocated as rank 1. As per GRA, optimal parameters related to rank 1. For this situation, optimal parameters for example current and T_{on}, T_{off} were 30 A, 45 μs and 5 μs, respectively. For these parameters, the tool wear rate was 1.866 mm^3/min, the MRR was 12.658 mm^3/min, and surface roughness value was 5.20 μm. By comparing these responses to other experiments, for Ra the lowest value of surface roughness was 4.09 μm which is somehow far from the optimum selected one. While the minimum TWR was found to be 1.866 g/min which is the same as the optimal. For the MRR, the maximum value was 17.69 mm^3/min which is far away from selected one of 12.658 mm^3/min. This is mean that, the optimal conditions will produce good surface finish with the less cost in tools as its corrosion is lower rate and moderate productivity. Least rank of 25 was found for the least GRG (0.47113). The parameters were 12 A, 150 μs and 5 μs, and the TWR of 6.486 mm^3/min with MRR of 13.32 mm^3/min and surface roughness value was 5.158 μm.

Table 4 GRA optimization

Exp. No.	Normalized responses			Division square			Grey coefficient			GRG	**RANK**
	TWR	MRR	Ra	TWR	MRR	Ra	TWR	MRR	Ra		
1	0.397872	0.016766	1	0.602128	0.983234	0	0.453668	0.337101	1	0.59692	**3**
2	0.356635	0.149573	0.870394	0.643365	0.850427	0.129606	0.437306	0.370253	0.794147	0.53390	**13**
3	0.301795	0.311986	0.720575	0.698205	0.688014	0.279425	0.417291	0.420871	0.641498	0.49322	**20**
4	0.277067	0.418332	0.599750	0.722933	0.581668	0.400250	0.408853	0.462249	0.555401	0.47550	**23**
5	0.197298	0.640090	0.403355	0.802702	0.359910	0.596645	0.383818	0.581456	0.455936	0.47374	**24**
6	0.521718	0	0.911497	0.478282	1	0.088503	0.511100	0.333333	0.849614	0.56468	**8**
7	0.475832	0.131178	0.785311	0.524168	0.868822	0.214689	0.488201	0.365278	0.699605	0.51769	**15**
8	0.416601	0.290923	0.638912	0.583399	0.709077	0.361088	0.461510	0.413539	0.580661	0.48524	**22**
9	0.386966	0.396678	0.521507	0.613034	0.603322	0.478493	0.449223	0.453177	0.510990	0.47113	**25**
10	0	0.950268	0.423566	1	0.049732	0.576434	0.333333	0.909534	0.464497	0.56912	**7**
11	0.658385	0.015610	0.804004	0.341615	0.984390	0.195996	0.594096	0.336839	0.718394	0.54978	**11**
12	0.606325	0.143814	0.681503	0.393675	0.856186	0.318497	0.559488	0.368681	0.610876	0.51301	**18**
13	0.541211	0.299198	0.538790	0.458789	0.700802	0.461210	0.521491	0.416388	0.520178	0.48602	**21**
14	0.237708	0.706444	0.516113	0.762292	0.293556	0.483887	0.396105	0.630075	0.508188	0.51146	**19**
15	0.153826	0.916190	0.312386	0.846174	0.083810	0.687614	0.371423	0.856444	0.421012	0.54963	**12**
16	0.816450	0.091160	0.666819	0.183550	0.908840	0.333181	0.731475	0.354902	0.600110	0.56216	**9**
17	0.755170	0.213697	0.548537	0.244830	0.786303	0.451463	0.671294	0.388711	0.525507	0.52850	**14**
18	0.463194	0.626992	0.494430	0.536806	0.373008	0.505570	0.482250	0.572732	0.497230	0.51740	**16**
19	0.426510	0.720536	0.370492	0.573490	0.279464	0.629508	0.465771	0.641466	0.442671	0.51664	**17**
20	0.334462	0.918378	0.170983	0.665538	0.081622	0.829017	0.428986	0.859664	0.376218	0.55496	**10**
21	1	0.305330	0.501385	0	0.694670	0.498615	1	0.418526	0.500694	0.63974	**1**
22	0.798802	0.613185	0.459731	0.201198	0.386815	0.540269	0.713066	0.563815	0.480645	0.58584	**4**
23	0.715511	0.741030	0.312348	0.284489	0.258970	0.687652	0.637358	0.658788	0.420999	0.57238	**6**
24	0.661480	0.825995	0.193959	0.338520	0.174005	0.806041	0.596289	0.741834	0.382837	0.57365	**5**
25	0.554112	1	0	0.445888	0	1	0.528604	1	0.333333	0.62065	**2**

For the determination of optimum values for EDM parameters which enhance the responses, a mean gray relational grade (MGRG) would be computed by containing all of the process input parameters to figure out the optimum inputs that give maximum MRR with minimum Ra and TWR. Calculations have been accomplished by considering two GRG value and averaging other two parameters, as shown in Table 5 and Fig. . Taking into account every parameter, the level having the most elevated MGRG is chosen as the optimal. From Table 5, highest GRG for (current, T_{on} and T_{off}) was found (30 A, 45 μs and 1 μs) respectively. Consequently, for acquiring lower TWR and Ra of the produced surface, the current should be as higher as possible while the T_{on} should be at the lowest value. Meanwhile T_{off} has no significant effect.

Table 5 MGRG of each parameter at every level

Parameters	**Unit**	**Average gray relation grade**				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Current (I)	Ampere	0.5147	0.5216	0.5220	0.5359	**0.5985**
T_{on}	µs	**0.5827**	0.5358	0.5109	0.5097	0.5536
T_{off}	µs	**0.5561**	0.5474	0.5379	0.5313	0.5198

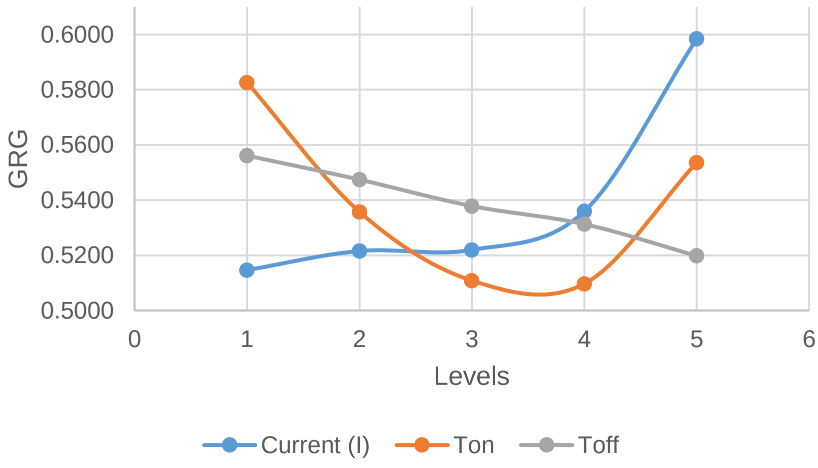


Fig. 7 Mean effect plot of process parameter on GRG

4.3. TOPSIS Analysis Results

Establishing the decision matrix, which comprises of the trials and process responses addressed as alternatives and attributes. An equal weight is allocated for each response as a value of 0.33 relative weight for TWR, MRR and Ra of the specimens. Finishing the TOPSIS methodology procedure, all determined qualities and values are shown in Table 6

Table 6 TOPSIS optimization.

Exp. No.	Normalized responses			Weighted normalized responses			Separation measures		CC	**RANK**
	TWR	MRR	Ra	TWR	MRR	Ra	S+	S-		
1	0.212689	0.151423	0.158912	0.070896	0.050474	0.052971	0.055616	0.050240	0.47461	**14**
2	0.223010	0.165207	0.170141	0.074337	0.055069	0.056714	0.048815	0.054055	0.52547	**12**
3	0.236736	0.182065	0.183121	0.078912	0.060688	0.061040	0.040418	0.059791	0.59666	**8**
4	0.242926	0.193102	0.193589	0.080975	0.064367	0.064530	0.035204	0.063095	0.64187	**6**
5	0.262891	0.216119	0.210604	0.087630	0.072040	0.070201	0.023700	0.072611	0.75392	**3**
6	0.181691	0.149683	0.166580	0.060564	0.049894	0.055527	0.061519	0.039986	0.39393	**19**
7	0.193176	0.163298	0.177512	0.064392	0.054433	0.059171	0.054717	0.044402	0.44797	**16**
8	0.208001	0.179878	0.190196	0.069334	0.059959	0.063399	0.046372	0.050786	0.52271	**13**
9	0.215419	0.190855	0.200367	0.071806	0.063618	0.066789	0.041290	0.054729	0.56998	**9**
10	0.312274	0.248314	0.208853	0.104091	0.082771	0.069618	0.012353	0.091208	0.88072	**1**
11	0.147484	0.151303	0.175893	0.049161	0.050434	0.058631	0.068676	0.029063	0.29735	**22**
12	0.160514	0.164609	0.186506	0.053505	0.054870	0.062169	0.061837	0.034469	0.35791	**20**
13	0.176812	0.180737	0.198870	0.058937	0.060246	0.066290	0.053562	0.041830	0.43851	**17**
14	0.252777	0.223006	0.200835	0.084259	0.074335	0.066945	0.026807	0.069552	0.72180	**4**
15	0.273772	0.244777	0.218485	0.091257	0.081592	0.072828	0.015953	0.079894	0.83356	**2**
16	0.107921	0.159144	0.187778	0.035974	0.053048	0.062593	0.077457	0.018359	0.19161	**24**
17	0.123259	0.171863	0.198026	0.041086	0.057288	0.066009	0.070432	0.025336	0.26455	**23**
18	0.196339	0.214760	0.202713	0.065446	0.071587	0.067571	0.043172	0.051861	0.54571	**11**
19	0.205521	0.224469	0.213451	0.068507	0.074823	0.071150	0.038395	0.056932	0.59723	**7**
20	0.228560	0.245004	0.230736	0.076187	0.081668	0.076912	0.028479	0.068308	0.70576	**5**
21	0.061980	0.181374	0.202111	0.020660	0.060458	0.067370	0.088023	0.017859	0.16867	**25**
22	0.419502	0.234185	0.223092	0.139834	0.078062	0.074364	0.066119	0.159138	0.70647	**2**
23	0.210382	0.259213	0.245826	0.070127	0.086404	0.081942	0.129283	0.111781	0.46370	**5**
24	0.143514	0.266363	0.269835	0.047838	0.088788	0.089945	0.150398	0.104950	0.41101	**7**
25	0.091786	0.289603	0.301706	0.030595	0.096534	0.100569	0.167065	0.110255	0.39757	**8**

The CC in TOPSIS is equivalent to the GRG in GRA. So, the alternative with the largest CC is considered to be the best solution. The trial no. 10 which has CC = 0.8870 is considered as the optimum solution. Calculation of the mean closeness coefficient (MCC) for all parameters is calculated as shown in

Table **7**. Additionally, the impact of each level of each parameter on the MCC value is illustrated in Fig. .

Table **7** demonstrates the mean response closeness coefficient with optimal process parameter level at every level.

Table 7 MCC of each parameter at every level

Parameters	**Unit**	**Average closeness coefficient**				
		Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Current (I)	Ampere	0.1071	0.2082	0.2883	0.4675	**0.5501**
T_{on}	µs	0.3504	**0.3548**	0.2997	0.3047	0.3116
T_{off}	µs	0.3498	0.266	0.2671	0.3259	**0.4125**

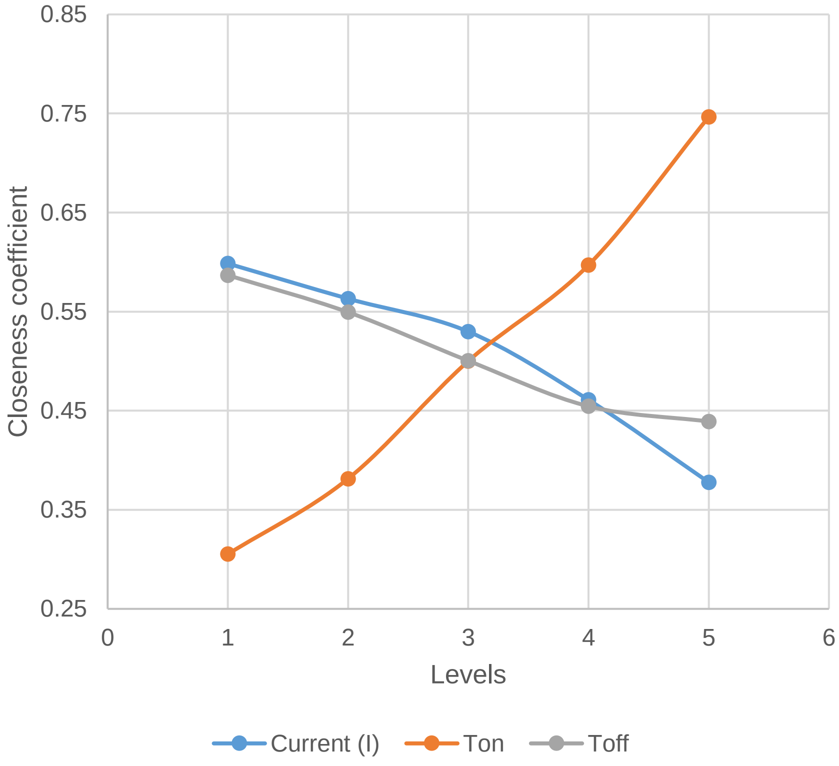


Fig. 8 Effect of current, T_{on} and T_{off} on closeness coefficient

4.4. Hybrid GRA-TOPSIS Analysis Results

Response weights were calculated. The obtained positive weights are 0.3252, 0.3105, and 0.3643 for the responses TWR, MRR, and Ra respectively. And the negative weights are 0.3389, 0.3571, and 0.3039. The weighted normalized decision matrix is given in Table 6. The PIS and NIS for every response is calculated by selecting the maximum or minimum value from the weighted normalized values for large the better and smaller the better responses respectively. Table 8 shows the computation of the hybrid GRA-TOPSIS technique.

Table 8 Hybrid GRA-TOPSIS weighted normalized decision matrix with closeness coefficient values and ranking of alternatives

Exp. No.	Normalized responses			Grey relational coefficients R_{ij}^{+}			Grey relational coefficients R_{ij}^{-}			Grey relational grade		R_i	RANK
	TWR	MRR	Ra	TWR	MRR	Ra	TWR	MRR	Ra	R_i^{+}	R_i^{-}		
1	0.397872	0.016766	1	0.432482	0.558550	1	0.582957	0.987740	0.315755	0.678390	0.646301	0.512112	**3**
2	0.356635	0.149573	0.870394	0.416302	0.593967	0.740474	0.609293	0.900305	0.346482	0.589573	0.633344	0.482104	**11**
3	0.301795	0.311986	0.720575	0.396571	0.643897	0.569596	0.648239	0.812364	0.390398	0.536404	0.628488	0.460475	**18**
4	0.277067	0.418332	0.599750	0.388273	0.681403	0.480223	0.667476	0.763530	0.434846	0.512790	0.631079	0.448294	**22**
5	0.197298	0.640090	0.403355	0.363722	0.775612	0.382634	0.738143	0.678480	0.533597	0.498504	0.654674	0.432287	**25**
6	0.521718	0.000000	0.911497	0.489636	0.554377	0.806887	0.515976	1	0.336109	0.625322	0.634160	0.496492	**6**
7	0.475832	0.131178	0.785311	0.466781	0.588796	0.632684	0.538918	0.911481	0.370127	0.565110	0.620665	0.476574	**13**
8	0.416601	0.290923	0.638912	0.440254	0.636953	0.505954	0.571733	0.822787	0.419370	0.525265	0.615081	0.460619	**17**
9	0.386966	0.396678	0.521507	0.428082	0.673416	0.435928	0.589698	0.772991	0.469459	0.507117	0.618611	0.450479	**21**
10	0.000000	0.950268	0.423566	0.314532	0.961561	0.390807	1	0.587020	0.521412	0.543224	0.707076	0.434475	**24**
11	0.658385	0.015610	0.804004	0.573233	0.558261	0.653586	0.457916	0.988575	0.364660	0.597859	0.619075	0.491283	**8**
12	0.606325	0.143814	0.681503	0.538229	0.592338	0.537262	0.478423	0.903774	0.403743	0.554678	0.607622	0.477224	**12**
13	0.541211	0.299198	0.538790	0.500037	0.639663	0.444995	0.506811	0.818661	0.461348	0.523337	0.604357	0.464077	**15**
14	0.237708	0.706444	0.516113	0.375759	0.809082	0.433174	0.700570	0.656596	0.472050	0.531224	0.615417	0.463287	**16**
15	0.153826	0.916190	0.312386	0.351606	0.936884	0.349716	0.783339	0.595845	0.596323	0.532646	0.659548	0.446778	**23**
16	0.816450	0.091160	0.666819	0.714278	0.577851	0.526040	0.405184	0.936778	0.408998	0.603336	0.596177	0.502984	**5**
17	0.755170	0.213697	0.548537	0.652076	0.612726	0.450276	0.424118	0.863403	0.456895	0.566336	0.590950	0.489366	**9**
18	0.463194	0.626992	0.494430	0.460856	0.769329	0.422444	0.545600	0.682974	0.482758	0.542642	0.575558	0.485282	**10**
19	0.426510	0.720536	0.370492	0.444480	0.816566	0.370050	0.565967	0.652129	0.554674	0.532896	0.593304	0.473181	**14**
20	0.334462	0.918378	0.170983	0.408093	0.938429	0.308466	0.624462	0.595270	0.729649	0.536465	0.646005	0.453682	**20**
21	1	0.305330	0.501385	1.000000	0.641686	0.425827	0.357392	0.815629	0.479270	0.679555	0.558070	0.549080	**1**
22	0.798802	0.613185	0.459731	0.695181	0.762816	0.406337	0.410461	0.687775	0.500942	0.610947	0.536989	0.532213	**2**
23	0.715511	0.741030	0.312348	0.617286	0.827700	0.349703	0.437345	0.645739	0.596353	0.585131	0.560087	0.510934	**4**
24	0.661480	0.825995	0.193959	0.575458	0.877293	0.314493	0.456752	0.620534	0.704071	0.574101	0.590402	0.493001	**7**
25	0.554112	1	0	0.507167	1	0.269962	0.500922	0.574601	1	0.573771	0.678907	0.458035	**19**

Optimum data is observed at trial no. 21 which highest proximity coefficient of 0.5491. It is noticed that optimum EDM parameters were the same in both GRA and GRA-TOPSIS. A current of 30A, and pulse duration T_{on} of 45 μs and pulse off-time T_{off} of 5 μs. Fig. and Table 9 shows the mean effects plot of closeness coefficient with respect to process parameters. From the mean effects plot, the optimum parameters combination that resulted in maximum closeness coefficient are (30 A, 45 μs and 1 μs) for (current, T_{on} and T_{off}) respectively.

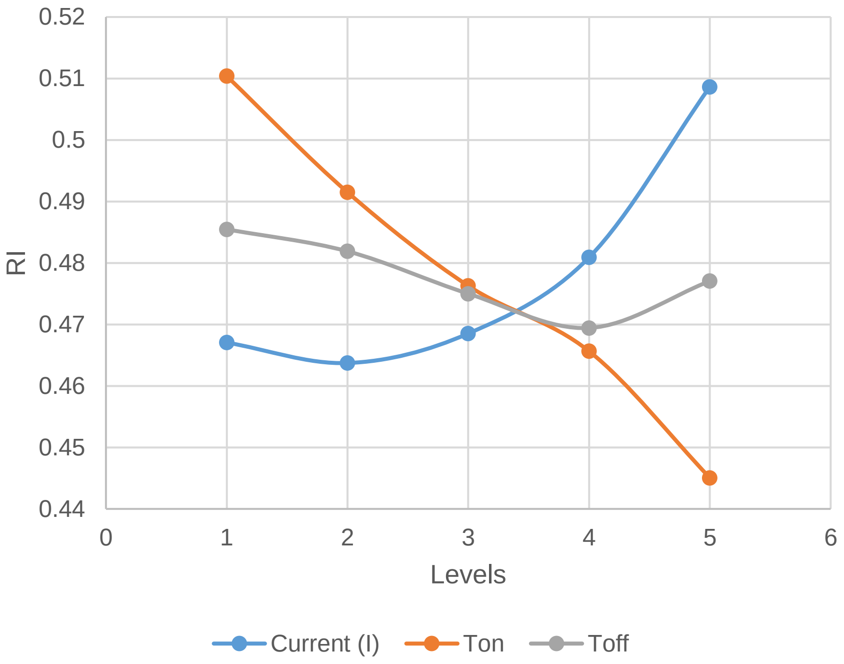


Fig. 9 Effect of current, Ton and Toff on closeness coefficient

Table 9 Mean response table for closeness coefficient

Parameters	**Unit**	Average closeness coefficient				
		Level 1	Level 2	Level 3	Level 4	Level 5
Current (I)	Ampere	0.4671	0.4637	0.4685	0.4809	**0.5087**
T_{on}	µs	**0.5104**	0.4915	0.4763	0.4656	0.4451
T_{off}	µs	**0.4855**	0.4819	0.4750	0.4694	0.4771

5. Conclusion

By enhancing the MRR and lowering surface roughness (Ra), as well as optimizing the process parametrs, the current study intends to improve the surface quality and productivity. The studies were carried out using Taguchi's Technique for design of experiments, which involved adjusting the current intensity (I), pulse on time (T_{on}), and pulse-off time (T_{off}). To discover the most important set of process variables, TOPSIS GRA and hybrid TOPSIS-GRA were used to accomplish multi-attribute optimization. The following are the results of the current study:

1) The electrode wear rate is calculated. Finally, it has to be mentioned (as a disadvantage) that the produced helical electrode is used once.
2) Utilizing three statistical methods GRA, TOPSIS, and TOPSIS-GRA, the optimal from these statistical approaches is converged to 30 A, 45 μs, 5 μs for I, T_{on}, T_{off} respectively.
3) The optimum parameters for GRA, TOPSIS, and hybrid TOPSIS-GRA are converged to a single combination.
4) The optimum parameters obtained from GRA and TOPSIS-GRA are the same. i.e., 30 A for current (I), 45 μs for (T_{on}), and 5 μs for (T_{off}).

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