Optimization of EDM Process Parameters using Taguchi and Grey-Based Taguchi Methods

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• **Abstract**—In manufacturing processes selection of conditions is one of the most important points to take into consideration in most of the manufacturing processes related to Electrical Discharge Machining (EDM). In electrical discharge machining, it is important to select machining parameters for achieving optimal machining performance. EDM is an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. This new research shares the difference between optimization processes Taguchi method and grey-based Taguchi method. The effect of the variable parameters mentioned above upon machining characteristics such as material removal rate (MRR), surface roughness (Ra), and power consumption will be carried out for optimization and investigation. This paper reviews the research work carried out from the inception to the development of good surface finishing and quality improvement & also briefly describing the current research technique trend in EDM, future EDM research direction

Keywords —. Taguchi method, Material removal rate, Surface roughness, ANOVA, Grey-based Taguchi optimization, H13, EDM

1 Introduction

EDM is a technology , makes significant inroads into the production of highly accurate, intricate and difficult to machine production parts. In electrical discharge machining, it is important to select machining parameters for achieving optimal machining performance. However, this does not ensure that the selected machining parameters result in optimal or near optimal machining performance. The Taguchi method can optimize performance characteristics through the settings of process parameters and reduce the sensitivity of the system performance to sources of variation. To improve the manufacturing process adopted the Grey based Taguchi method, which is solving the multi-object optimize problem. Through grey based Taguchi method, we hope to create a model which can optimize multiple performance characteristics for the EDM process.

To prevent excessive heating, electricity is supplied as short pulses. Spark is where the gap between the tool and the workpiece surface is the smallest. A spark material, the difference increases to a different point on the surface of the work-piece shifts the position of the spark is removed later.

In EDM, since there is no direct contact between the work piece and the electrode, hence there are no mechanical forces existing between them. In this process the material is removed from the work piece due to erosion caused by rapidly recurring electrical spark discharge between the work piece and the tool electrode. There is a small gap between the tool and the work piece. The work piece and tool both are submerged in dielectric fluid, commonly used are EDM oil, de-ionized water, and kerosene.

2 METHODOLOGY

- Identifying the process parameters and performance measures
- Identifying the number of levels for the process parameters and possible interactions between them
- Selecting the orthogonal array and assigning the process parameters
- Conducting the experiments based on the orthogonal array
- Calculating of S/N ratio
- Analyzing the results using S/N ratio and ANOVA ratio
- Selecting Optimal levels of process parameters
- Calculation by using grey relation analysis process.
- Performing the confirmation experiment to verify the results

2.1 S/N RATIO

In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factor. The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different signal-to-noise ratios, depending on the goal of your experiment. For static designs, Minitab different four signal-to-noise ratios.

2.2 TAGUCHI METHOD

A large number of experiments have to be carried out as the number of the process parameters increases. To solve this, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. A larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. A statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. The optimal combination of the process parameters can then be predicted based on the above analysis.

1	Determining A Function
2	Identifying Factors And Their Levels
3	Selecting An Orthogonal Array
4	Performing The Experiments
5	Calculating S/N Ratio
6	Analyzing
7	Confirming Experiment

Steps To Perform Taguchi Method

The significant of this method is:
- To find controllable level of factors in a process;
- To achieve effective factor level combinations through orthogonal array deign; and
- To reduce error or quality losses.

2.3 GREY BASED TAGUCHI METHOD

The integrated grey based Taguchi method combines both the algorithms of **Taguchi method** and **Grey Relational Analysis** to determine the optimum value of process parameters with multiple performance characteristics. The grey system theory is a new methodology that helps to solve such real life problems. It deals with relational analysis and model construction through model generating, excavating, and extracting useful information from what is available.

The Grey Relational Analysis Approach

To improve the manufacturing process adopted the Taguchi method, which is solving only single objective optimize problem. To overcome this Taguchi method coupled with grey relation analysis, which is used to solve multi response optimization problem. Relationship between process parameter and response variable can be found out with the help of grey relational analysis.

Step 1 :- Normalizing the Response,

Larger is better

MRR and Power Consumption

$$X_i^*(K)=(X_i(K)-\min X_i(K))/(\max X_i(K)-\min X_i(K))$$

Smaller is better

Ra

$$X_i^*(K)=(\max X_i(K)-X_i(K))/(\max X_i(K)-\min X_i(K))$$

Step 2:- Calculate deviation sequence

$$\Delta oi(K)= |X_o^*(K)-X_i^*(K)|$$

$X_o^*(K)= 1$ Maximum normalised value

Step 3:- Determination of Grey relation coefficient (GRC)

GRC(K) for the Kth performance characteristics in Ith experiment can be expressed as follows

$$R_i (K)= (\Delta\min+R\Delta\max)/(\Delta oi(K)+R\Delta \max)$$

Where,

$\Delta\min= \min|X_o^*(K)-X_i(K)|= |1-1|= 0$

$\Delta\max= \max|X_o^*(K)-X_i(K)|= |1-0|= 1$

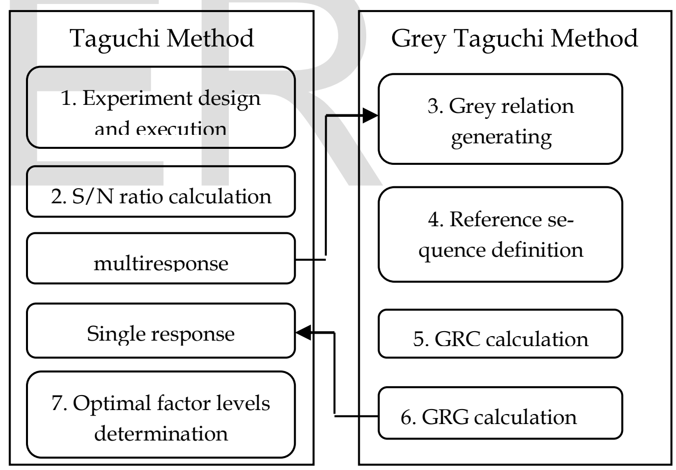
R = distinguishing coefficient and generally set as 0.5.

Step 4:- Calculate grey relational grades,

$$Y_i=\sum W_i(K)*R_i(K)$$

Where,

$W_i(K)$= Weightage given to response variable



3 EXPERIMENTAL SETUP

In the study experiments were carried out on make Sparkonix EDM; model Sparkonix MOS 35. The dielectric flow system was modified for circulation of dielectric fluid suspended dielectric medium in small quantities to prevent contamination of whole of dielectric fluid.

- H13 (specimen 70mm X 70mm X 30mm) was selected as work piece. For conducting the experiments, it has been decided to follow the Taguchi method and grey Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables.

- The effect of suspended fluid on the phenomenon of surface modification should be studied in order to correctly understand its behavior. Hence, it was decided to conduct experiments with each combination of work material, electrode and fluid.
- Out of the above listed design variables, the orthogonal array was to be selected for three design variables (namely pulse on-time, gap voltage and current) which would constitute the orthogonal array.
- Preliminary experiments were conducted in the given range of different input parameters to select their levels. L16 orthogonal array has been used which contains 16 experimental runs at various combinations of five input variables .
- Machining rate is measured in term of volume of material eroded from work piece per minute by weight loss method as per following equation.
- Experimental data were evaluated statistically by analysis of variance (ANOVA) and all other machine parameters were kept constant during the time of experiment.

3.1 WORK PIECE DETAILS :-

- Work piece material :- H13
- Length of work-piece :- 20 mm
- Diameter of work-piece :- 28 mm
- EDM used :- Sparkonix MOS 35A
- Tool material :- Copper
- Depth of throat :- 250
- Dielectric fluid used :- Kerosene oil

Figure 1: Copper Electrode used in experiment

3.2 TOOL DETAILS

- The tool electrode is most critical part of the EDM and therefore we are using **copper** as tool material for our experiment.
- Copper has been choosen as the electrode material because of its lower electrical and thermal resistance.
- It provides the best durability and cost.
- Copper has better EDM wear resistance than others.
- It has better strength and offers inferior oxidation resistance.
- Melting point of pure copper is 1085 °C.

3.3 MATERIAL USED

H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications. Because of its excellent combination of high toughness and resistance to thermal fatigue cracking (also known as heat checking) H13 is used for more hot work tooling applications than any other tool steel .

ELEMENT	Cr	C	Mn	P	S	Si	Ni
WEIGHT	1.79	0.38	1.45	0.0012	0.002	0.37	0.90

Table 1: Chemical composition of H13 tool steel

H-13 properties:-

- Good resistance to abrasion at both low and high temperature
- High level of toughness and ductility
- Uniform and high level of machinability and polishability
- Good high temperature strength and resistance to thermal fatigue
- Excellent through-hardening properties
- Very limited distortion during hardening

3.4 VARIABLE INPUT PARAMETERS

Based on the machine control the levels of input factors are finalized. Their are three process parameter such as pulse on time, gap voltage and pulse current were taken and see their effect on performance parameter such as MRR(mm3/min),

Table 2:- Levels of input control factors with units

surface roughness(Ra) and Power Consumption(W).

3.4 ANALYSIS OF VARIANCE

- ANOVA is commonly used to investigate whether the experimental design parameter have a significant effect on the responses.

- Analysis of Variance (ANOVA) was performed on balanced data for wide variety of experimental design. ANOVA calculates the F-ratio, which is the ratio between the regression mean square and the mean square error.
- If the calculated value of F-ratio is higher than the tabulated value of F-ratio for MRR and Surface roughness, then the model is adequate at desired α (error term) level to represent the relationship between machining responses and machining parameters.

- These analyzes were done by using MINITAB software version-18.

4 RESULT AND DISCUSSION

S/N ratios is used to measure quality distinctive from desired value. S/N ratio for MRR, Power Consumption was calculated based on larger is better condition as described below,

$$S/N= -10*\log(\sum(1/Y^2)/N)$$

S/N ratio for Surface Roughness was calculated based on smaller is better condition as described below,

$$S/N = -10*\log(\sum(Y^2)/N)$$

Where,

N= No of experiment and Y is measured value based on

S/N ratio were obtained for surface roughness and MRR

MRR is calculated using equation

MRR = Mass(before)-Mass(after)/(Time*Density)

Factors	EDM Machining Parameters	Levels				Observed
		L1	L2	L3	L4	
A	Pulse -on time (µs)	15	30	50	75	1.Material removal rate (mm3 /min)
B	Gap voltage (volts)	35	40	45	50	2.Surface Roughness(Ra)
C	Pulse Current (Ampere)	5	7	9	11	3.Power consumption (W)

Sr no	PULSE ON TIME(µs)	GAP VOLTAGE (volts)	PULSE CURRENT (A)	MATERIAL REMOVAL RATE,MRR (mm3/min)	SURFACE ROUGHNES , Ra(µm)	POWER CONSUMPTION (W)	S/N ratio, MRR	S/N ratio, Ra	S/N ratio, power cons.
1	15	35	5	9.52	6.18	2.11	19.5727	-15.8198	6.48565
2	15	40	7	7.25	5.24	1.85	17.2068	-14.3866	5.34343
3	15	45	9	6.04	4.35	1.62	15.6207	-12.7698	4.19030
4	15	50	11	7.86	5.35	1.89	17.9085	-14.5671	5.52924
5	30	35	7	9.88	4.20	2.31	19.8951	-12.4650	7.27224
6	30	40	5	9.74	5.38	2.25	19.7712	-14.6156	7.04365
7	30	45	11	8.59	4.25	1.99	18.6799	-12.5678	5.97706
8	30	50	9	9.39	3.32	1.02	19.4533	-10.4228	0.17200
9	50	35	9	8.16	5.05	1.88	18.2338	-14.0658	5.48316
10	50	40	11	7.71	5.23	1.86	17.7411	-14.3700	5.39026
11	50	45	5	8.41	4.53	2.08	18.4959	-13.1220	6.36127
12	50	50	7	9.01	4.48	2.02	19.0945	-13.0256	6.10703
13	75	35	11	9.32	6.23	2.08	19.3883	-15.8898	6.36127
14	75	40	9	7.25	5.25	1.85	17.2068	-14.4032	5.34343
15	75	45	7	8.26	4.28	1.91	18.3396	-12.6289	5.62067
16	75	50	5	9.51	5.24	2.10	19.5636	-14.3866	6.44439

Table3 : S/N ratio value of experimental results

Analysis of Material Removal Rate experiments were conducted using L16 Orthogonal Array to find the effect of process parameters on the MRR. The experiments were done on H13 Steel. The rate of cutting speed for each work piece and tool materials were collected in same experimental conditions. After performing experiment MRR value is recorded in each experiment shown in Table 3.

4.1 Analysis Of Material Removal Rate, Surface Roughness And Power Consumption by TAGUCHI METHOD

- Experiments were conducted using L16 Orthogonal Array to find the effect of process parameters on the MRR, Ra and Power Consumption.
- After performing experiment MRR, Ra and Power Consumption value is recorded in each experiment shown in Tables.
- Analysis of variance (ANOVA) is performed and signal-tonoise (S/N) ratio will be determined to know the level of importance of the machining parameters.
- S/N ratio are calculated and graph for analysis is drawn by using MINITAB 17 software. The S/N ratio for MRR, Ra and Power Consumption is calculated on MINITAB 17 Software using Taguchi Method.

4.1.1 Analysis of MRR

To obtain the optimal machining performance the higher the better quality characteristics for MRR. As can be seen from Table (above), the MRR is most significantly influenced by the Ton followed by the Gap Voltage. The greater average S/N ratio corresponds to the max MRR. From the S/N response graph Fig, it is concluded that the optimum parametric combination is Ton (30), Pulse Current (5A), and Gap Voltage (35V). In other words, it is this combination of parameters that gives the max MRR for the machined material. Figure shows the interaction between the pulse current, pulse on and gap voltage. Mean data interaction for material removal rate (MRR).

4.1.2 Analysis of variance (ANOVA) for S/N Ratio w.r.t MRR

Model Summary

S	R-Sq	R-Sq(adj)
0.3888	95.59%	88.99%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pulse on time	3	7.1230	7.1230	2.3743	15.71	0.003
gap voltage	3	6.5312	6.5312	2.1771	14.40	0.004
pulse current	3	6.0227	6.0227	2.0076	13.28	0.005
Residual Error	6	0.9069	0.9069	0.1511		
Total	15	20.5838				

naly-
sis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. After finding all the observation as given in Table, S/N ratio are calculated and graph for analysis is drawn by using MINITAB 17 software. The S/N ratio for MRR is calculated on MINITAB 17 Software using Taguchi

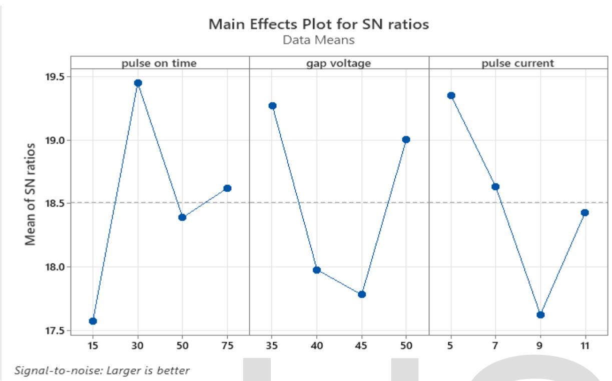
Method. The S/N response graph for Material Removal rate.

Response Table for Signal to Noise Ratio Larger is better

Response Table for Signal to Noise Ratios

Larger is better

Level	pulse on time	gap voltage	pulse current
1	17.58	19.27	19.35
2	19.45	17.98	18.63
3	18.39	17.78	17.63
4	18.62	19.00	18.43
Delta	1.87	1.49	1.72
Rank	1	3	2



The table includes ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response

4.2 Analysis of Surface Roughness

Experiments were conducted using L16 Orthogonal Array to find the effect of process parameters on the SR. The experiments were done on H13 Steel. The rate of cutting speed for each work piece and tool materials were collected in same experimental conditions. After performing experiment Ra value is recorded in each experiment shown in Table

4.2.1 Analysis of variance (ANOVA) for S/N Ratio w.r.t TWR

Model Summary

S	R-Sq	R-Sq(adj)
0.6078	92.42%	81.05%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pulse on time	3	9.051	9.051	3.0169	8.17	0.015
gap voltage	3	10.048	10.048	3.3494	9.07	0.012
pulse current	3	7.926	7.926	2.6421	7.15	0.021
Residual Error	6	2.217	2.217	0.3695		
Total	15	29.242				

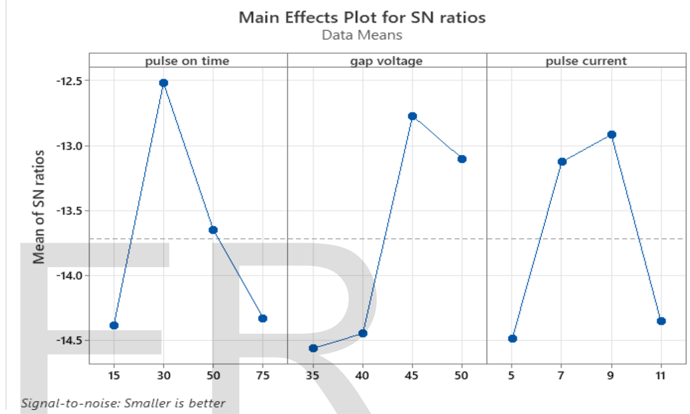
According to the Minitab software the graphs show that best values of parameters are Ton (30), Pulse Current (9A) ampere and gap voltage (45V) but, these values do not lie in orthogonal array L16 table.

4.2.2 Response Table for Signal to Noise Ratio Smaller is better

Response Table for Signal to Noise Ratios

Smaller is better

Level	pulse on time	gap voltage	pulse current
1	-14.39	-14.56	-14.49
2	-12.52	-14.44	-13.13
3	-13.65	-12.77	-12.92
4	-14.33	-13.10	-14.35
Delta	1.87	1.79	1.57
Rank	1	2	3



The Table includes ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response.

4.3 Analysis of power consumption

An ANOVA was performed to obtain the percentage contribution of each factor effect on Power Consumption.

4.3.1Analysis of variance (ANOVA) for S/N Ratio w.r.t power consumption

Model Summary

S	R-Sq	R-Sq(adj)
1.4602	67.67%	19.17%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pulse on time	3	1.794	1.794	0.5980	0.28	0.838
gap voltage	3	6.995	6.995	2.3318	1.09	0.421
pulse current	3	17.985	17.985	5.9950	2.81	0.130
Residual Error	6	12.793	12.793	2.1322		
Total	15	39.567				

It was observed that pulse current with contribution of 45.45%

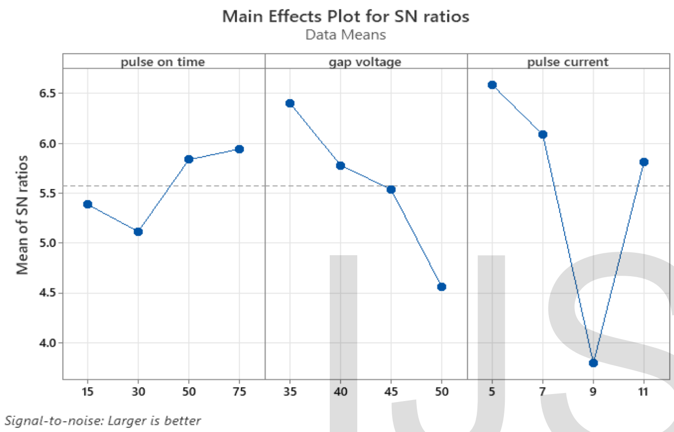
has the highest influence on Power Consumption followed by Gap Voltage with 17.67% and pulse on time 4.55%

4.3.2 Response Table for Signal to Noise Ratio Smaller is better

Response Table for Signal to Noise Ratios

Larger is better

Level	pulse on time	gap voltage	pulse current
1	5.387	6.401	6.584
2	5.116	5.780	6.086
3	5.835	5.537	3.797
4	5.942	4.563	5.814
Delta	0.826	1.837	2.787
Rank	3	2	1



5 Analysis Of MRR, Ra And Power Consumption by GREY BASED TAGUCHI METHOD

- We know that these method is combination of taguchi and grey relation analysis approach.
- Therefore first we are going to calculate the grey relation analysis and culculate their grade and decide rank positions.
- Then by the data of that calculation the final graph and S/N ratio of MRR, Ra and Power Consumption is calculated based on mixed level orthogonal array
- These analyzes were done by using MINITAB software by taguchi method.

5.1 CALCULATIONS:
Calculations of normlization and deviation sequence:

Sr. No.	MRR	Ra	Power Consumption	normalization MRR	normalization Ra	normalization Power consumption	Deviation Sequence MRR	Deviation Sequence Ra	Deviation Sequence Power Consumption
1	9.52	6.18	2.11	0.90625	0.01718	0.84490	0.09375	0.98282	0.15510
2	7.25	5.24	1.85	0.31510	0.34020	0.64340	0.68490	0.65980	0.35660
3	6.04	4.35	1.62	0.00000	0.64600	0.46510	1.00000	0.35400	0.53490
4	7.86	5.35	1.89	0.47396	0.30240	0.67440	0.52604	0.69760	0.32560
5	9.88	4.2	2.31	1.00000	0.69000	1.00000	0.00000	0.31000	0.00000
6	9.74	5.38	2.25	0.96354	0.29200	0.95340	0.03646	0.70800	0.04660
7	8.59	4.25	1.99	0.66400	0.68040	0.75190	0.33600	0.31960	0.24810
8	9.39	3.32	1.02	0.87230	1.00000	0.00000	0.12770	0.00000	1.00000
9	8.16	5.05	1.88	0.55200	0.40540	3.12400	0.44800	0.59460	-2.12400
10	7.71	5.23	1.86	0.43480	0.34360	0.65110	0.56520	0.65640	0.34890
11	8.41	4.53	2.08	0.61710	0.58410	0.82170	0.38290	0.41590	0.17830
12	9.01	4.48	2.02	0.77340	0.60130	0.77510	0.22660	0.39870	0.22490
13	9.32	6.23	2.08	0.85410	0.00000	0.82000	0.14590	1.00000	0.18000
14	7.25	5.25	1.85	0.31510	0.33670	0.64340	0.68490	0.66330	0.35660
15	8.26	4.28	1.91	0.57800	0.67010	0.68990	0.42200	0.32990	0.31010
16	9.51	5.24	2.1	0.90360	0.34020	0.83720	0.09640	0.65980	0.16280
Min	6.04	3.32	1.02	0	0	0	0	0	-2.124
Max	9.88	6.23	2.31	1	1	3.124	1	1	1

5.2 Grey Relational Coefficient and Grey Relational Grade (GRG):

sr. no.	Grey Relational Coefficient- GRC MRR	Ra	Power Consumption	Grade	Rank
1	0.84211	0.33720	0.76324	0.38851	5
2	0.42198	0.43111	0.58370	0.28736	13
3	0.33333	0.58548	0.48314	0.28039	15
4	0.48731	0.41750	0.60562	0.30209	11
5	1.00000	0.61728	1.00000	0.52346	1
6	0.93204	0.41391	0.91475	0.45214	2
7	0.59809	0.61005	0.66836	0.37530	7
8	0.79656	1.00000	0.33333	0.42598	3
9	0.52743	0.45679	-0.30788	0.13527	16
10	0.46940	0.43238	0.58900	0.29815	12
11	0.56632	0.54591	0.73714	0.36987	8
12	0.68814	0.55636	0.68975	0.38685	6
13	0.77411	0.33333	0.73529	0.36855	9
14	0.42198	0.42981	0.58370	0.28710	14
15	0.54230	0.60248	0.61721	0.35240	10
16	0.83836	0.43111	0.75438	0.40477	4

5.3 RESPONSE TABLE FOR GRADE:

parameters	Level 1	Level 2	Level 3	Level 4	**Rank (max/min)**
pulse on time(μs)	0.239065	**0.444220**	0.297540	0.353205	1(0.146680)
gap voltage(volts)	0.353273	0.331188	0.344490	**0.379923**	2(0.048735)
pulse current(A)	**0.403823**	0.387518	0.387518	0.336173	3(0.016305)
Avg	**0.354828**				

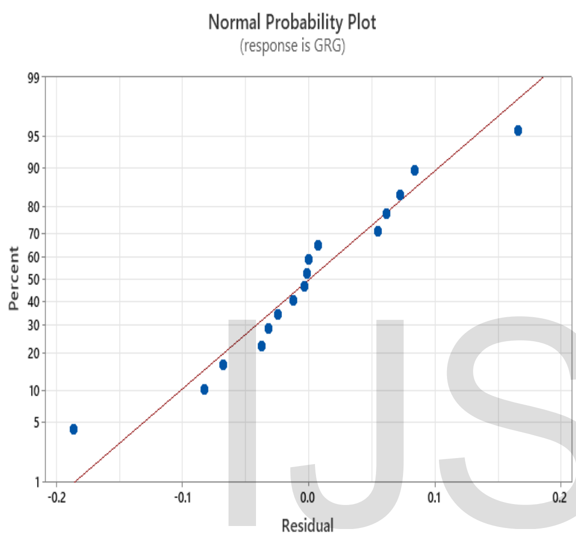
5.4 ANOVA OF GRG(with graph):

Model Summary

S	R-Sq	R-Sq(adj)
2.2160	71.75%	29.38%

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pulse on time	3	36.263	36.263	12.088	2.46	0.160
gap voltage	3	5.266	5.266	1.755	0.36	0.786
p c	3	33.311	33.311	11.104	2.26	0.182
Residual Error	6	29.465	29.465	4.911		
Total	15	104.306				



6. CONCLUSION:

1) Gap Voltage has a greater influence on the surface Roughness followed by Ton Time. Pulse Current had the least influence on Roughness.
2) Ton Time is the most significant parameter for Material Removal Rate, followed by Pulse Current and Gap Voltage respectively.
3) Use of grey based Taguchi method is greatly helpful to optimize the multi-objective machining performance characteristics and the problem can be significantly simplified;
4) This study indicated that grey based Taguchi technique is not only a novel, efficient and reliable method of optimization, but also contributes to a satisfactory solution for multi-objectives process

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