Vol. XV & Issue No. 06 June - 2022
INDUSTRIAL ENGINEERING JOURNAL

PARAMETRIC OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINING ON NIMONIC 90

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Abstract

Present study is based to optimize the machining parameters of electric discharge machining (EDM) of super alloy NIMONIC 90. The main objective behind the present work is to get better metal removal rate (MRR) and surface finish (SR) under optimal conditions. The results of experimental study were validated using Taguchi and Grey Relational Analysis (GRA) method and found to be significant. It showed that MRR sharply increased with the increase on pulse on time and decreased with the decrease in pulse off time.SR also increased as pulse on time increases up to a middle value then SR started decreasing. Experimental run number 2 found to be more suitable for the maximum surface finish 3.66 (µm) compromising the MRR. It is worth mentioning that the experimental run number 7 is preferred for the applications oriented towards higher MRR of the order of 0.20 g/min compromising surface finish.

Keyword: Nimonic 90, Electric Discharge Machining, Taguchi, Grey Relational Analysis (GRA)

1. INTRODUCTION

The recent developments in manufacturing industries has led to the demands for advanced materials such as composites, ceramics, and super alloy. The present work is focused on super alloy Nimonic 90 which is having multiple functional characteristics. Therefore, the unique properties of these materials make them widely applicable in nuclear engineering, aerospace industries, sports, and marine application [1]. It is also used in the aerospace, nuclear and chemical industries [2]. Nimonic 90 alloy is difficult to machine by conventional machining processes because of their high hardness and brittleness, so it is machined with non-conventional machining processes [3]. Gas turbine blade, Pulp and paper industry components such as pump casing, washer, Heat-treating equipment such as tray, fixtures and conveyor belts are the other application of Nimonic 90 [4]. Nimonic 90 alloys are a group of nickel-chromium-cobalt based super-alloys that exhibit such as high resistance to corrosion, oxidation, carburization, pitting, corrosion cracking, and high temperature strength [5]. Nimonic alloys are precipitation hardenable metal. Nickel-chromium-cobalt alloy strengthened by the addition of Titanium and Aluminium. Nimonic 90 has a high stress rupture strength and creep-resistant at temperatures up to 920^{0}C [6,7]. The properties of Nimonic 90 are high tensile, creep, and rupture strength, outstanding fatigue, thermal-fatigue strength and oxidation resistance [6,7]. The advanced materials are a class of engineering materials which provides improved technical properties. Nimonic 90 is typically used in extreme stress applications such as turbine blades, hot working tools, exhaust reheaters and disc at high temperature.

Machining problems of Nimonic 90 have been identified after the literature survey, an effort has been made to bridge them through the present study. Literature review reveals that the researcher has carried out most of the work on EDM developments, monitoring and control but very limited work has been reported on parameters optimization of NIMONIC 90.The effect of machining parameters on NIMONIC 90 has not been fully explored using EDM with brass electrode. There is a need to enhance performance characteristics of work material NIMONIC 90 while performing on EDM. Multi response optimization of EDM process is another thrust area which needs further attention. Identifying the most effective controllable factors in relation to Material removal rates (MRR) and the Surface roughness (SR), The objectives of the problem were formulated asto study and analyses the effect of Peak current (I_p), Pulse on time (T_{on}), Pulse off time (T_{off}) on Material removal rate and Surface Roughness and to establish optimal parametric setting to obtain better result of performance characteristic.

2. EXPERIMENTAL DEVICES AND METHODS

In present study, work material in the shape of plates of Nimonic 90, (140x80x8mm) size were used. Nimonic 90 has tensile strength of 1251 MPa, compressive strength of 2200 MPa and hardness value of 250-350 HV. The experiments were performed on SPARKONIX S50ZNC EDM machine installed in machine shop of Mechanical Engineering Department at SLIET Longowal. A brass electrode of 10 mm diameter was used as tool electrode. Electric Discharge Machining, is a thermal material removal process in which electrical energy is used to generate electrical spark and material removal mainly occurs due to absorption of thermal energy from the sparks which leads to localized heating, melting and vaporization of the material. In EDM, both tool and work material acts as conductors of electricity and are maintained at a potential difference, the system of tool and workpiece is immersed in a dielectric fluid (generally kerosene or de-ionized water). The tool acts as the negative terminal and the workpiece is connected to positive terminal of the generator.

In the present work, The following process parameters peak current (I_p), Pulse on time (T_{on}), Pulse off time (T_{off}) have been considered. Thus, each process parameter was assigned three levels base on the preliminary experiments conducted. The process parameters along with their levels, considered in the present study are shown in table 1.

Table 1: Process parameters and their levels

Factor	Name	Symbol	Unit	Levels		
A	Peak Current	I_p	A	9	12	15
B	Pulse On Time	T_{on}	µs	30	60	90
C	Pulse Off Time	T_{off}	µs	2	3	4

Grey relational analysis is a normalization-based evaluation technique require a sample of only limited size, of discrete sequential data to enable reliable modeling and estimation of system behavior. Multiple performance objectives are in high demand of the industrial field, and the analysis is complicated due to demand for the large measured value. Since, the original Taguchi method is only possible to optimize single performance objective [9]. Experiments were conducted as per Experimental Lay out of using L9(3^3) Orthogonal array mentioned in table2.

Table 2: Experimental Lay out of using L9 (3^3) Orthogonal array

Run	Peak Current I_p(A)	Pulse On Time T_{on} (µs)	Pulse Off Time T_{off} (µs)
1	9	30	2
2	12	30	3
3	15	30	4
4	12	60	2
5	15	60	3
6	9	60	4
7	15	90	2
8	9	90	3
9	12	90	4

Each experiment ran as per orthogonal array and were repeated twice in order to reduce experimental error. Thus, total 18 experiments performed and Kerosene was used as dielectric for all the experiments.

Following steps were followed in the cutting operation

1. The tool was made vertically with the help of upper and lower guide block.
2. The work piece was mounted and clamped to the worktable.
3. A reference point on the work piece was set for setting work coordinate system (WCS).

3. RESULTS AND DISCUSSIONS

The performance measure MRR & SR were calculated. The experimental results have been shown in the Table 3

Table 3: Experimental result

Run	Peak Current I_p(A)	Pulse-on Time Ton(µs)	Pulse off time Toff(µs)	Performance Measures			
				MRR g/min	MRR g/min	SR µm	SR µm
1	9	30	2	0.06551	0.07567	7.33	4.46
2	12	30	3	0.091282	0.066256	6.46	3.66
3	15	30	4	0.064288	0.0005123	5.13	6.2
4	12	60	2	0.03833	0.096426	7.6	8.73
5	15	60	3	0.13659	0.112508	6.93	8.46
6	9	60	4	0.061387	0.046202	7.168	5.76
7	15	90	2	0.2007168	0.1453488	5.2933	6.933
8	9	90	3	0.09496	0.108374	6.42	5.81
9	12	90	4	0.09264	0.128534	7.2	6.9

In grey relational grade, data pre-processing is done to perform linear normalization that is known as grey relational generated as shown in Table 4. The experimental results were analyzed that are given in a series of standardized steps through Grey Relational Analysis (GRA).

Table 4: Normalization of the experimental result performance for MRR and SR

Exp. Run	Data Normalizing			
	MRR		SR	
Ideal value	1	1	1	1
1	0.167378	0.5189	o.1093	0.8422
2	0.326085	0.4539	0.4615	1
3	0.159852	0	1	0.49901
4	0	0.6622	0	0
5	0.602943	0.77325	0.2712	0.0532
6	0.1398327	0.3154	0.16761	0.5857
7	1	1	0.933	0.3544
8	0.348772	0.7447	0.4777	0.5759
9	0.3344	0.883	0.1619	0.3609

In Grey relational generation, the normalized result of metal removal rate (MRR), follow larger-the-better (LB) criterion which is expressed as:

$$x_{\text{i}}(k) = \frac{y_{\text{i}}(k) - \min y_{\text{i}}(k)}{\max y_{\text{i}}(k) - \min y_{\text{i}}(k)} \quad \textbf{(2)}$$

In Grey relational generation, normalized result of Surface finish follow smaller-the-better (SB) criterion which is expressed as:

$$x_{\text{i}}(k) = \frac{\max y_{\text{i}}(k) - y_{\text{i}}(k)}{\max y_{\text{i}}(k) - \min y_{\text{i}}(k)} \quad \textbf{(3)}$$

Grey relational grade (GRG) is calculated by averaging the relational coefficient corresponding to each performance measures and expressed as:

$$\mathrm{r_i} = \frac{1}{\mathrm{m}} \sum_{\mathrm{j=1}}^{\mathrm{m}} \xi_{\mathrm{i}}\, \mathrm{j} \quad \textbf{(4)}$$

Thus, by applying Eq. 4, all grey relational grade computed, which provide an alternative ranking. Here value determines a better alternative. Thus, the higher GRG represents that the corresponding result is closer to the ideal normalized value. The GRG obtained for each experimental run and the ranking order of the experiment is shown in table 5. It is seen that experimental run 2 has the best multiple performance characteristics among 9 runs performed because higher values of GRG give a better machining performance. It follows from data that experimental run 7&1 can be ranked 2&3 respectively.

Table 5: GRG for each experimental run

RUN	GRG	ORDER
1	O.63485	3
2	0.73895	1
3	0.41475	9
4	0.4634	8
5	0.5167	6
6	0.4844	7
7	0.718225	2
8	0.60152	5
9	0.624655	4

The effect of each process parameter of Nimonic 90 on the grey relational grade at different level separated because the experimental design L_9 orthogonal array is used. The mean of grey relational grade for the peak current (I_p) at level 1, 2 and 3 was calculated by averaging the grey relational grade for experiments 1 to 3, 4 to 6, 7 to 9, respectively. GRG for $T_{on,}$ T_{off} and I_p were calculated in a similar manner. The difference between maximum and minimum value of GRG was calculated and ranked accordingly as shown in table 6.

Table 6: Response Table for Grey Relational Grade

Levels	I_p (A)	T_{on}(µs)	T_{off}(µs)
1	0.57359	0.5961	0.596183
2	0.609001	0.488166	0.619056
3	0.54989	0.64813	0.597935
Delta	0.059111	0.159967	0.111121
Rank	3	1	2

The differences in values of the averages GRG of the machining parameters are as follows $I_{P\,avg}$= 0.05911A, $T_{on\,avg}$= 0.159967 µs, and $T_{off\,avg}$= 0.111121 µs . Pulse on time has the most effective, controllable factor having the maximum value of 0.159967 µs as per table 5. Among the other process parameters used to study the multi-performance characteristics, followed by the pulse off time and peak current. The greatest GRG value gives the optimal parametric setting like peak current (Level 2), pulse on time (Level 3), pulse off time (level 2) respectively **A2B3C2** which gives better results of performance characteristic.

3.1 Effect on MRR

Figure1, subplot-1 it is revealed that as the value of pulse on time increases from 30 to 60 µs**,** MRR increases rapidly then decreases mildly from 60 to 90 µs. Subplot 2-, As value of pulse off time 2 to 3 µs increases, the MRR decreases moderately and further increase of pulse off time from 3 to 4 µs, MRR decreases rapidly. Subplot 3-, it is evident that when the value of peak current increase from 9A to 12A, MRR increases and then decreases when further peak current increase from 12A to 15A. As MRR directly proportional for small range of peak current. Further increasing peak current, it increases the spark discharge hence increases no. of spark. This leads to decrease in MRR and surface roughness. When no. of spark has been increased less local heat produced which melt and vaporized the work piece very slowly resulting in lower MRR. Whereas in figure 2, Subplot-1, As pulse on time increases from 30 to 60 µs, MRR increases at slow rate. When pulse on time increases from 60 to 90 µs, MRR increases at higher rate than previous one. Subplot-2 As pulse off time increases from 2 to 3 µs, MRR decreases at slower rate. When pulse off time is from 3 to 4 µs. Then MRR decreases at higher rate than previous one. Subplot-3 As peak current increases from 9A to 12A. MRR increases then decreases from 12Ato 15A.

That the influence of single parameter on MRR.MRR sharply increase with increase in pulse on time. MRR decreases with decrease in pulse off time. As pulse current increases up to the middle value MRR increases and then start decreasing. Thus, the highest MRR obtain at middle value of peak current.

Figure 1. Main effect plot for SN ratio of MRR

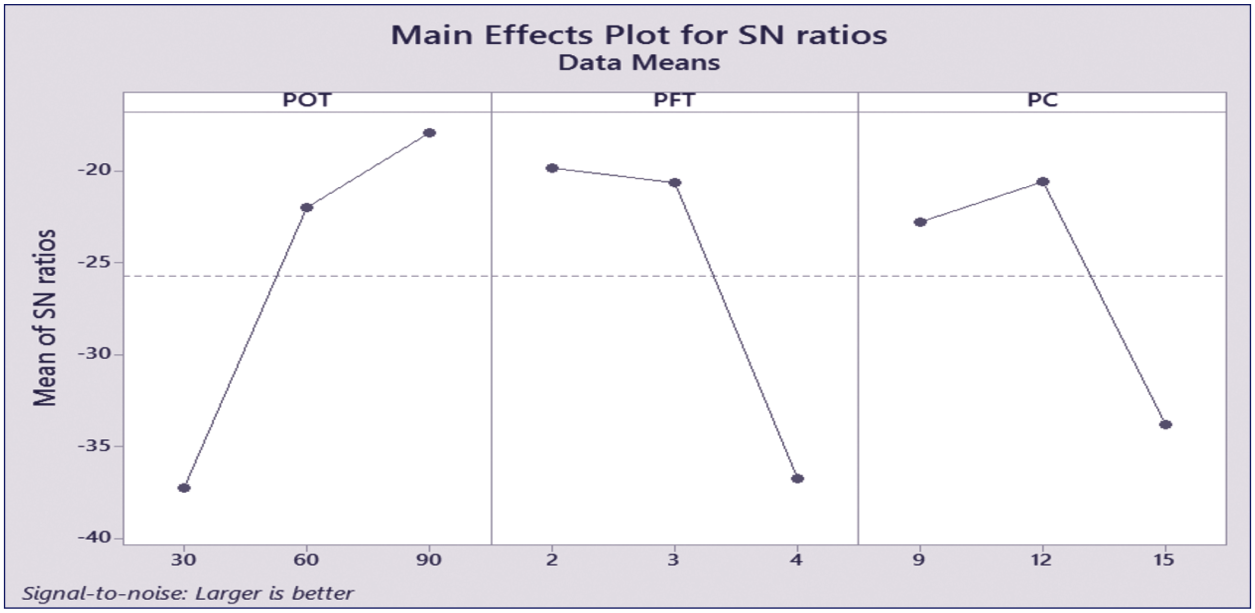
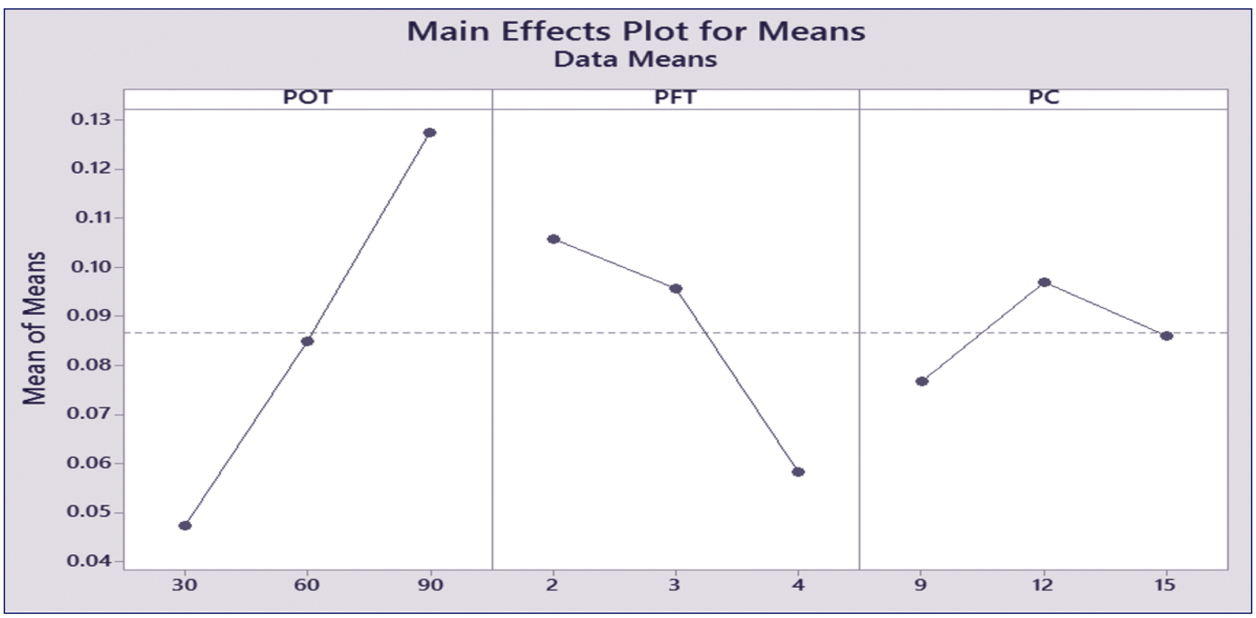


Figure 2. Main effect plot for means of MRR



3.2 Effect on SR

Figure 3. Subplot-1 As pulse on time increases from 30 to 60 µs, SN ratio decreases then increases from 60 to 90 µs. Subplot-2, As pulse off time increases from 2 to 3 µs, SN ratio increases then decreases from 3 to 4 µs. Subplot-3, As peak current increases from 9Ato12A, SN ratio decreases at slower rate than that of 12Ato 15A. Whereas in figure 4. subplot-1 As pulse on time increases from 30 to 60 µs, SR increases then decreases when further increase pulse on time from 60 to 90 µs. Subplot-2, As pulse off time increases from 2 to 3 µs, SR decreases and when pulse off time increases from3 to 4 µs, SR increases. Subplot-3, As peak current increases from 9 to 12 µs, SR increases at higher rate than that of 12A to 15A. The influence single input parameter on SR. SR increases as pulse on time increases up to middle value then SR start decreasing for further increment in the pulse on time . Pulse off time having exact opposite effect on SR as pulse off time increases up to middle level SR decrease and then start increasing. After middle level, SR increases sharply as peak current increases.

Figure 3. Main effect plot for SN ratio of SR

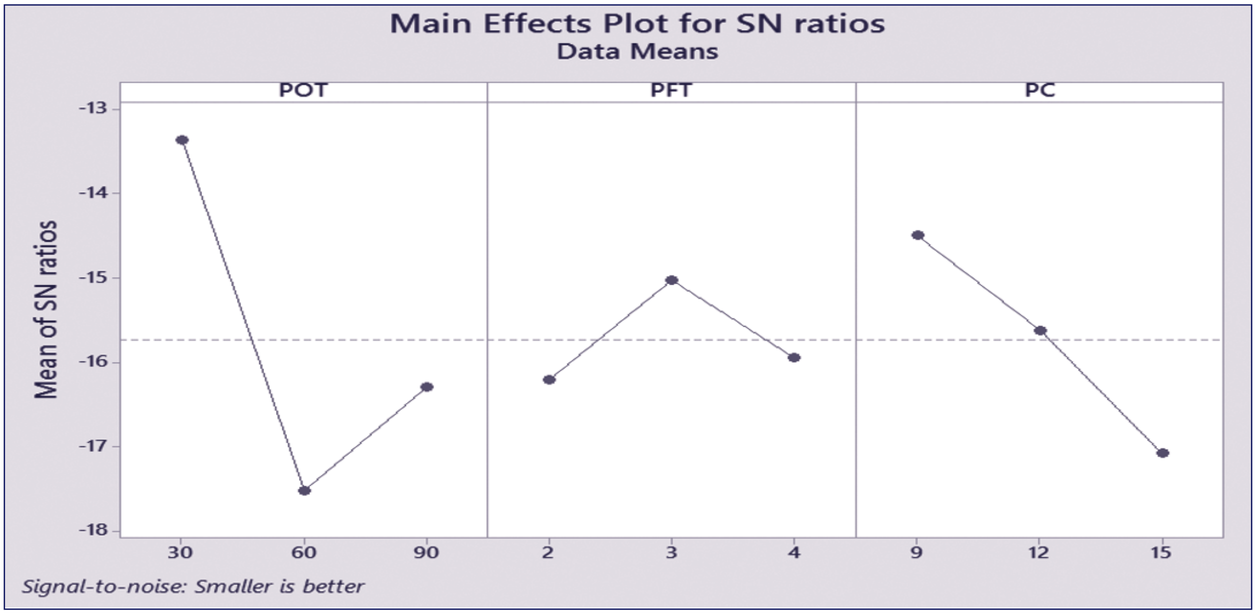
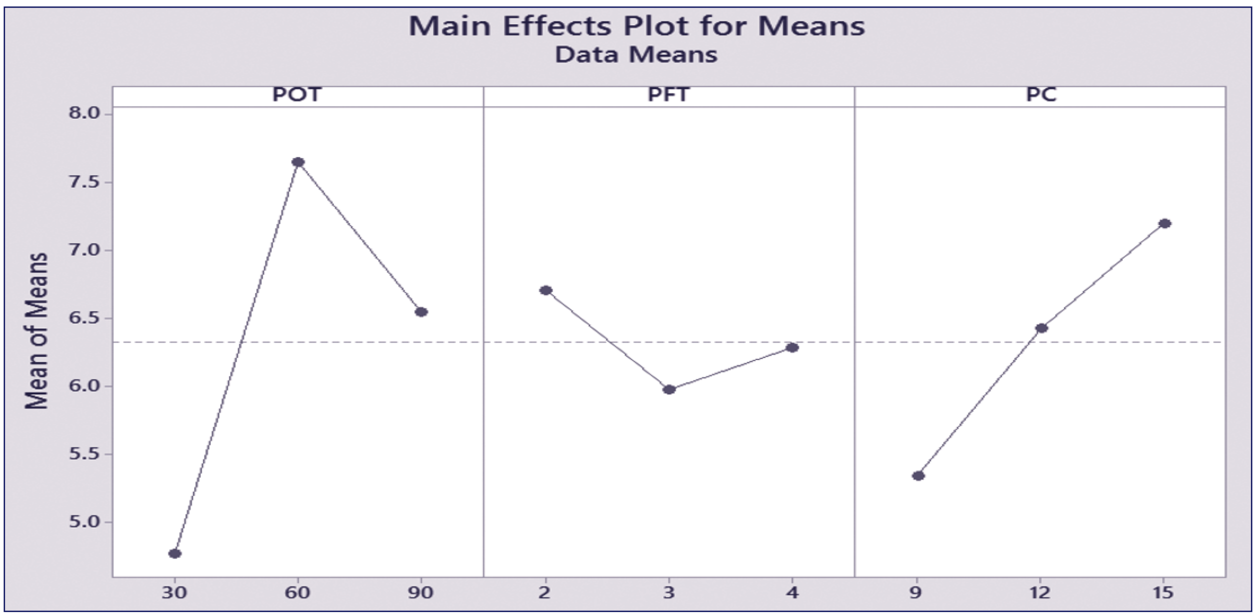


Figure 4. Main effect plot for means of SR.



3.3 Conformation Tests

To validate the results of the experiment, conformation test conducted as per optimal parameters settings. The optimal parameters in our experimentation in case of material removal rate (MRR) were A2B3C2, it means the optimum parameters setting for higher MRR is to set peak current at 12A, pulse off time 3µs, pulse on time 90µs and to use brass electrode. The conformation experiments for higher material removal rate (MRR) have been performed on aforesaid conditions and MRR was found to increase on those particular conditions as suggested by main effect plots. Similarly the optimal parameters in case of surface roughness were A2B3C2, it means the optimum parameter setting for lower surface roughness is: peak current at12A, pulse on time at 90µs and pulse off time 3µs and brass electrode for machining. Conformation experiments for lower surface roughness have been performed on the aforesaid conditions. After the conformation test it was found that the surface roughness was improved quite satisfactorily at the optimum conditions suggested by the main effect plots.

4. CONCLUSION

The Taguchi Based Gray Relational Analysis (TGRA) was adopted to optimize the complicated interrelationship among multi-performance characteristics. It was observed that TGRA greatly simplifies the multi-optimization, and moreover does not require any complex mathematical objective computations. The various conclusions which were observed are given below:

1. The greatest GRG value provides an optimal parametric setting are peak current (Level 2), pulse on time (Level 3), pulse off time (Level 2), which means that the optimal

process parameters are, 12 A peak current, 90µs pulse of time and 3µs pulse off time.

2. The response table for grey relational grade makes ranks which decides the most effective parameters, namely pulse on time (rank 1), peak current (rank 3), and pulse off time (rank2).
3. The pulse on time has the strongest effect among the other process parameters used to study the multi-performance characteristics, followed by pulse off time and peak current.
4. When pulse on time and peak current increases, higher MRR was achieved due to larger discharge energy.
5. The surface roughness has an increasing trend with the increasing pulse on time and peak current.

- The greatest GRG value provides optimal parametric settings for the peak current (Level 2), the pulse on time (Level 3) and the pulse off time (Level 2), which means that the optimal process parameters are 12A peak current, 90µs pulse on time, 3µs pulse off time
- The response table 9 for grey relational grade makes rank which decides the most effective parameters namely pulse on time (rank 1), peak current (rank 3), and pulse off time (rank2).
- Pulse on time has greatest effect among other process parameters used to study the multi-performance characteristics, followed by pulse off time and peak current respectively. When the pulse on time and peak current increases, MRR also increases due to the large discharge energy.
- The surface roughness increases with increase in pulse on time and peak current.

4.1 Future Scope:

- The effect of other process parameters such as spark gap voltage, flushing pressure, conductivity of dielectric, tool diameter, may also be investigated.
- Efforts should be made to investigate the effects of EDM process parameters on performance measures in a cryogenic cutting environment.
- Other optimization technique like response surface methodology (RSM), artificial neural network etc, may be used to optimize all the process parameter of Nimonic 90.

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