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Effect and Optimization of Process Parameters using Taguchi Method in WEDM for AISI M42 HSS Material

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Abstract: ***The most popular and an inevitable non-conventional machining process used for the machining of hard and difficult-to-cut material such as tungsten carbide and its composites is Wire cut EDM or WEDM process. Higher productivity, accuracy and reliability are the most important goals of WEDM to achieve. Due to a large number of variables and improper combination of process parameters, the optimal performance of WEDM processes is very difficult to achieve. This goal can be achieved by determining the relationship between the process parameters and response variables of the WEDM process and selecting the optimum process parameters. The objective of current research work is to determine the optimum process parameters i.e., pulse on time (Ton), pulse off time (Toff), wire feed rate (Wf) and their effect on the response variables i.e., material removal rate (MRR), surface roughness (Ra), kerf width (KW) in WEDM for AISI M42 HSS material using Taguchi method and ANOVA. The study reveals that, the most significant factors for MRR, SR are Ton followed by Toff. Wire feed rate is significant for KW and interaction of Toff and Wf also plays significant role. Wire feed rate is insignificant for MRR.***

Keywords: WEDM, Process Parameters, Response Variables, Optimization, DOE, Taguchi method, etc

1. Introduction

The extreme demands in the field of aerospace, turbine, automobile, tool and die manufacturing sector leads to new research in advanced engineering materials which has opened new opportunities for the manufacturing sector. The materials such as tungsten carbide and its composites, titanium based alloys and other superalloys – have been developed to meet these extreme demands. The traditional metal cutting processes utilizes shearing action on the work piece for material removal during machining. The properties such as high hardness, toughness, corrosion resistant have made these advanced materials difficult-to-cut using traditional metal cutting processes. Hence, the machining of difficult-to-cut materials is a critical issue for the industries in the field of manufacturing [1-5] and machining of them can open up opportunities of utilizing them widely. Nowadays innovative research and developments in the area of non-traditional machining processes such as Wire Electro-Discharge Machining (WEDM) process are considered as alternative replacements for conventional machining methods of metal working. WEDM has the capability of machining the intricate features of hard and difficult-to-cut materials such as tungsten carbide with high dimensional accuracy between ±2μm to ±3μm which has made WEDM process the most popular and an inevitable non-conventional machining process [1,2]. Both EDM and micro-EDM processes in recent years have been extensively used in the field of mould making, production of dies and cavities etc. for aerospace, nuclear, missile, turbine, automobile, tool and die making industries.

WEDM was first introduced in the late 1960's to manufacturing sector. WEDM as shown in Figure 1 is a thermal-based process in which the spark is generated between workpiece and tool i.e., conductive wire (usually brass wire of diameter 0.25mm).

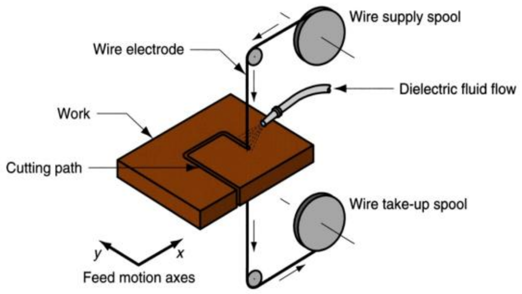

Figure 1: WEDM Setup

The workpiece and tool electrode are connected in electrical circuit and high frequency DC pulses are discharged from the wire tool to the work piece. Material removal takes place due to rapid and repetitive spark discharges (more than thousand times per second) between workpiece and tool electrode [3-5]. In EDM system, the electrode is driven with extreme accuracy by a servo-driven system controlled by a microprocessor. The gap of 0.025 to 0.075 mm is continuously maintained between the wire and workpiece using this servo controlled mechanism [3]. Liquid dielectric medium usually deionized water is continuously passed in the gap provided between the wire and workpiece which also act as a coolant. The wire is continuously fed during machining process. Huge amount of heat is generated (about 10,000 ^{O}C) due to sparking, which is sufficient to melt or vaporize the workpiece material and the molten mass is removed by flushing of dielectric thus, tool profile is transferred to work piece. WEDM is used for machining of newer and difficult to machine materials [8-13], such as hardened steel, High Speed Steel (HSS), High Strength Low Alloy (HSLA) steel, Metal Matrix Composite (MMC) etc. This process enables machining of any type of feature such as deep, blind, inclined and micro holes and complicated profiles with highest accuracy and surface finish.

The most important goals of WEDM are to achieve a higher productivity (i.e., MRR) and accuracy (i.e., Ra, KW). Due to a large number of variables and improper combination of process parameters, the optimal performance for these response variables is very difficult to achieve [3, 4]. This goal can be achieved by determining the relationship between the process parameters and response variables of the WEDM process and selecting the optimum process parameters [1-5]. In the recent years numerous studies have reported an investigation on parametric optimization of WEDM process for different materials using various Design of Experiments (DOE) techniques [6-13].

2. Literature Review

Researchers have used different analytical and statistical methods to analyze different combinations of process parameters to determine the most significant/optimum process parameter. Some of the important and extensively used methods by researchers in industry are Taguchi method, Regression Analysis Method, Particle Swarm Optimization (PSO), Response Surface Methodology (RSM), Central Composite Design (CCD), Grey Relational Analysis (GRA), and Grey-Fuzzy Logic etc [6-13].

During these studies a variety of process parameters such as peak current, gap voltage, pulse on time, pulse off time, polarity and wire feed rate etc. have been optimized by investigating there effect on response variables such as MRR, Ra, KW, cutting rate, WWR and dimensional deviation etc. through controlled experiments [1-5]. It can be observed in literature review. The literature review reveals about the effect of single and multi process parameters on different response variables in WEDM.

K. P. Rajurkar *et al.* [1] reviewed the two major electro-machining processes with unique capabilities i.e., the Electrochemical Machining (ECM) and Electro-Discharge Machining (EDM) processes. The study reveals that, both the machining processes i.e., EDM and ECM offer a better and the only alternative in machining of difficult to machine materials. The technological and economical comparison of rough milling operation of titanium and nickel based alloys reveals that, depending on the geometry, ECM is as good as in machining titanium alloy. For smaller batch sizes EDM has been found to be a better choice, whereas for large scale production ECM is more suitable choice.

M. P. Jahan *et al.* [2] evaluated both the electrodischarge machining (EDM) process and Micro-EDM. The study reveals that, EDM has the capability of machining hard and difficult-to- cut material such as tungsten carbide and its composites with high dimensional accuracy and intricate features which has made EDM process most popular and an inevitable non-conventional machining process. Both EDM and micro-EDM processes in recent years are used extensively in the fields such as mould making, production of dies and cavities. The study reveals about current research trends in EDM and micro-EDM of tungsten carbide, there problems and challenges and the importance of compound and hybrid machining processes.

Joshi Guruprasad R. et al. [3] reviewed the current research work on parametric optimization in WEDM. The study reveals that due to a large number of variables and improper combination of process parameters, the optimal performance of WEDM processes is very difficult to achieve. This goal can be achieved by determining the relationship between the process parameters and response variables of the WEDM process and selecting the optimum process parameters. Researchers have used different analytical and statistical design of experiment (DOE) methods to select best combination of process parameters for determining the most significant/optimum process parameter. Study also reveals that the most important goals of WEDM are to achieve a higher productivity (i.e., MRR) and accuracy (i.e., Ra, KW). Pulse-on-time is the most influential factor for all the response variables such as MRR, Ra, and KW. After pulse on time, higher pulse off time was observed to be next significant parameter for KW and SR. The value of kerf width decreases with decrease in pulse-off time and wire feed rate.

U. A. Dabade *et al.* [4] made an attempt to analyze the machining conditions for MRR, SR, cutting width (kerf) and dimensional deviation during WEDM of Inconel 718 using L8 orthogonal array Taguchi method. The result of the study reveals that, pulse-on-time is the most influential factor for all the response variables such as MRR, SR, Kerf. High pulse-on time (TON) results in faster erosion of the material as longer duration of spark results in higher spark energy release that leads to increase in size of craters formed hence increase in MRR and SR was observed. Peak current was observed to be next significant parameter for kerf and dimensional deviation whereas for MRR and SR, servo voltage was observed to be the next significant parameter.

Pujari Srinivasa Rao *et al.* [5] presented an investigation on a parametric analysis of wire EDM parameters for residual stresses in the machining of aluminum 2014 T6 alloy using L8 orthogonal array Taguchi method by considering input parameters viz., pulse on time (Ton), peak current (Ip) and spark gap voltage (Sv). The result of the study reveals that, the surface roughness and cutting speed increases with increase of pulse on time and peak current. The surface roughness decreases with the increase of spark gap voltage. The spark gap voltage with pulse on time and peak current had a significant effect on the residual stresses. The value of residual stress and surface roughness increases with an increase in cutting speed.

Feng Yerui *et al.* [6] examined EDM process parameters using TiC/Ni metal ceramic material for the influence of peak current, pulse duration on the surface roughness, MRR and material removal mode (MRD). Experimental result indicates that the surface roughness and material removal rate increases gradually with the increase of peak current also, the surface roughness and MRR of the workpiece increases with the increase of pulse duration. The change of pulse duration has little effect on the MRD.

Giovanna Gautier *et al.* [7] evaluated the interactions between common process parameters of WEDM and final quality of the generated surface, through analysis of variance

(ANOVA) and regression models based on experimental results. The paper focuses on the effects of Ton, Toff, SV and wire tension (WT) on the surface finish (Ra) during the WEDM of a Gamma-TiAl alloy. Analysis of results shows that, the factors Ton, SV and WT show significant effect on Ra. In particular, lower levels of Ton and WT give maximum Ra and the lowest value of SV gives the minimum Ra.

S. Assarzadeh et al. [8] optimized process parameters viz., discharge current, pulse-on time, duty cycle and gap voltage in terms of MRR, TWR and Ra for tungsten carbide-cobalt composite (WC/6%Co) material (Iso grade: K10) using RSM in EDM. Based upon previous data and available literature, the levels of pulse on time were maintained between 25µs to 125µs and duty cycle between 40 to 80%. The result of the study reveals that, Current, duty cycle and pulse on time are the most significant factors for MRR, Ra and TWR. The MRR increases by selecting both higher discharge current and duty cycle. Duty cycle of 49% is the optimal value found during investigation. The TWR can be minimized by applying longer pulse on-time with lower current intensities while smooth work surfaces are attainable with small pulse durations with higher levels of discharge currents.

I. Puertas et al. [9] carried out a study on the influence of the factors of intensity (I), pulse time (ti) and duty cycle (η) over the surface roughness, material removal rate (MRR) and electrode wear using factorial design in EDM. The ceramic used in this study was cemented carbide i.e., 94WC–6Co. Based upon previous data and available literature, the levels of duty cycle were maintained between 40%-60%. The study reveals that, the value of MRR increases when intensity (Current) increases and, moreover, this increase becomes more pronounced as the value of duty cycle rises at 60% due to the existence of an interaction between the two factors.

K. Jangra et al. [10] investigated the influence of important WEDM parameters on machining performance of WC-Co composite using RSM using four input parameters: pulse-on time, pulse-off time, servo voltage and wire feed and three output performance characteristics – cutting speed (CS), surface roughness (SR) and radial overcut (RoC). Based upon previous data and available literature, the levels of pulse on time were maintained between 108µs to 122µs, pulse off time between 30µs to 50µs, wire feed rate between 4 to 8m/min and servo voltage between 20V to 40V. The study reveals that, cutting speed and surface roughness increases with increasing pulse on time and wire feed rate at lower servo voltage, while it decreases with increasing pulse off time and higher servo voltage.

S. H. Lee et al. [11] studied the influence of operating parameters of EDM such as gap voltage, discharge current, pulse on time, pulse off time, dielectric flushing pressure and 3 tool electrodes on MRR, relative wear ratio and surface finish using WC. The result of the study reveals that, current, pulse on time and pulse off time are the most significant factors for MRR and surface roughness. The optimum condition of MRR, relative wear ratio and surface roughness for precision machining of Tungsten carbide takes place at discharge current of 24A pulse Duration (pulse on time) of 100µs and pulse interval (Pulse off time) of 100µs.

A. Chandrakanth et al. [12] presented an investigation of M42 HSS grade material in WEDM for optimization of three process parameters namely pulse on time (Ton), wire tension and spark gap voltage (SV) in terms of MRR using full factorial design, ANOVA and RSM. Based upon previous data and available literature, the levels of pulse on time were maintained between 110µs to 130µs and spark gap voltage between 20V to 60V. The study reveals that, the most significant factors for metal removal rate are Ton, SV and interaction of Ton and SV also plays significant role. Wire tension is very less significant for metal removal rate.

Saman Fattahi et al. [13] investigated the effects of different types of gas (air, nitrogen, and mixture of argon/air) on the machining characteristics of dry EDM of M35 workpiece material using six control factors, including current, pulse on-time, duty factor, gas pressure, electrode rotational speed and type of gas on machining responses, including material removal rate (MRR), surface roughness and radial overcut. A Taguchi L27 orthogonal array design was used to conduct the experiments. Based upon previous data and available literature, the levels of pulse on time were maintained between 100µs to 300µs, duty cycle between 40 to 86% and current between 14 to 30A. The study reveals that, three process parameters namely current, pulse-on time and duty cycle were the most significant factors for MRR and SR. The confirmation experiment shows that, Pulse on time of 100µs, duty cycle of 40% and current of 14A levels were selected as the multi objective optimized levels.

Here the study reveals that most of the researchers have investigated the effect of a limited number of process parameters on the response variables in WEDM. Pulse on time followed by pulse off time is significant for MRR and SR. The effect of machine process parameters on AISI M42 HSS material has not been fully explored using WEDM with constant current and voltage condition. AISI M42 is premium cobalt high speed steel with a chemical composition designed for high hardness and superior hot hardness. The composition of AISI M42 HSS makes it excellent in wear resistance by virtue of high heat-treated hardness (68 to 70 hrc), and the high cobalt content imparts the hot hardness. Therefore the investigation of effect of different process parameters on AISI M42 HSS is very important.

3. Experimental Setup and Procedure

3.1 DOE based on Taguchi method

Classical experimental design methods are too complex and are not easy to use. A large number of experiments have to be carried out when the number of process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. In current research work Taguchi design of experiments as shown Figure 2 have been used.

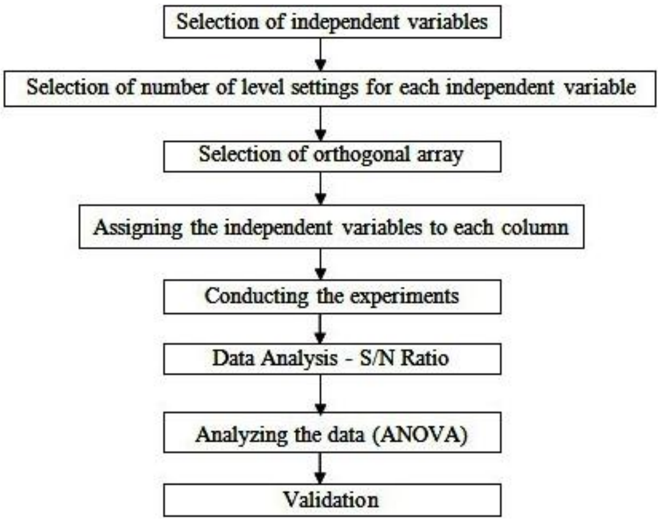

Figure 2: Taguchi design of experiment flow chart

The CNC Wirecut EDM Machine Electronica - Maxicut 734 has been selected for current research work. AISI M42 HSS material with a size of 10 x 10 x 200 mm has been selected as a workpiece material for research work. Taguchi DOE is used to form L18 orthogonal array for the experimentation. In each experimental run 6 mm x 6 mm square punch has been cut from the work piece on the CNC Wirecut EDM Machine. Brass wire of 0.25mm diameter with deionized water as dielectric fluid has been used during machining process. Based upon pilot experiment and literature review following process parameters and levels have been selected for conducting the main (major) experiment as shown in Table 1. Figure 3 shows the details of experimental setup.

Table 1: Process parameters with levels

Process parameters	Unit	Levels		
		Level 1	Level 2	Level 3
A - wire feed rate (Wf)	m/min	4	6	-
B - pulse on time (Ton)	µs	108	111	114
C - pulse off time (Toff)	µs	50	53	56

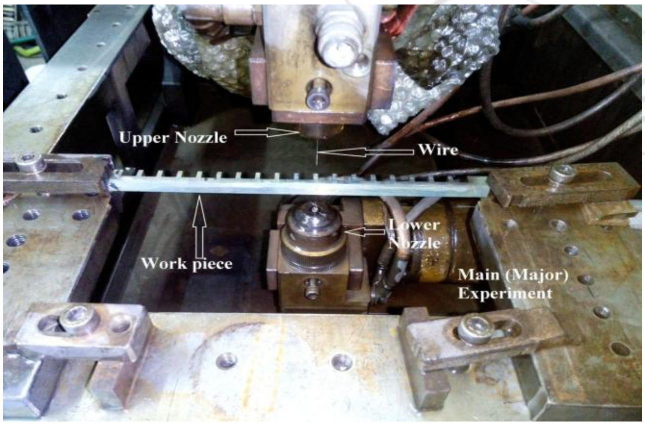

Figure 3: Experimental setup with work piece

3.2 Measurement of Response Variables

MRR has been calculated by taking product of kerf width, cutting speed and thickness of material as shown in equation (1). Here Heidenhain make electronic probe with DRO have been used to measure the kerf width and thickness of material. Kerf width was calculated by taking the difference between dimensions (thickness) of workpiece before and after machining as shown in Figure 4. The cutting speed was recorded directly from control panel of the machine.

$$MRR = KW * Vc * Mt \qquad (1)$$

Where: KW = Kerf Width in mm, Vc = Cutting Speed in mm/min, Mt= Thickness of Material in mm

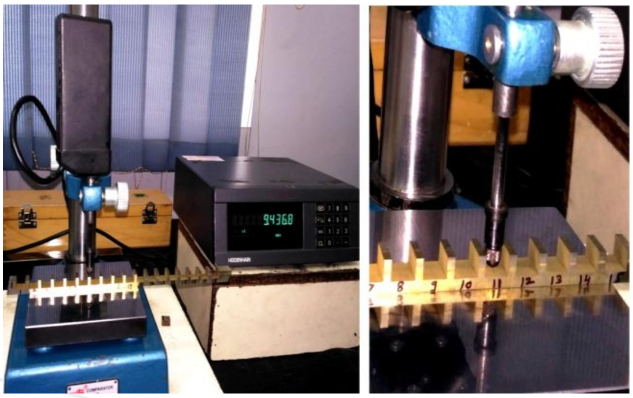

Figure 4: Heidenhain make electronic probe with DRO with enlarged probe

The surface roughness values have been measured by using a Mitutoyo make SJ-201 surface roughness tester. For each test four values have been recorded. After measurement, the arithmetic mean of four data values have been calculated and used as an absolute value.

4. Result and Discussion

Based upon data collected during pilot experiment and available literature the parametric levels have been selected and these levels have been used to conduct the main (major) experiment. Using Taguchi method the L18 orthogonal array has been generated.

Table 2: L18 Orthogonal Array (OA)

Sr. No.	Wire Feed Rate (Wf)	Pulse On Time (Ton)	Pulse Off Time (Toff)
1	4	108	50
2	4	108	53
3	4	108	56
4	4	111	50
5	4	111	53
6	4	111	56
7	4	114	50
8	4	114	53
9	4	114	56
10	6	108	50
11	6	108	53
12	6	108	56
13	6	111	50
14	6	111	53
15	6	111	56
16	6	114	50
17	6	114	53
18	6	114	56

Experiments have been conducted as per L18 orthogonal array as shown in Table 2. The experimental results for MRR, SR and KW have been collected after conducting the lab test and following results were obtained during the main experiment as shown in Table 3.

Table 3: Experimental results

Sr. No.	Response Variables		
	MRR (mm^3/min)	SR (Ra in µm)	KW (mm)
1	4.1729	3.17	0.32041
2	3.5290	3.02	0.31703
3	2.7857	2.97	0.29811
4	5.2859	3.21	0.29826
5	4.3539	3.08	0.28663
6	3.6449	3.04	0.28208
7	6.8818	3.4	0.29431
8	5.6123	3.36	0.28991
9	4.8898	3.19	0.28616
10	3.8435	2.9	0.29986
11	3.2256	2.83	0.29768
12	2.6192	2.67	0.28548
13	5.5151	3.18	0.30633
14	4.4675	3.15	0.29923
15	3.8377	3.07	0.29893
16	7.2020	3.29	0.31701
17	6.0823	3.24	0.30288
18	5.2894	3.07	0.30283

The data collected during main (major) experiment have been analyzed in Minitab-17 software to calculate S/N ratio and plot graph for response variables. Table 4 shows the S/N ratios calculated for response variables.

Table 4: S/N Ratio for Response Variables

Sr. No	S/N Ratio For Response Variables		
	MRR (mm^3/min)	SR (Ra in µm)	KW (mm)
1	12.40871	-10.02119	9.88588
2	10.95304	-9.60014	9.97799
3	8.89871	-9.45513	10.51247
4	14.46236	-10.13010	10.50810
5	12.77751	-9.77101	10.85357
6	11.23366	-9.65747	10.99255
7	16.75400	-10.62958	10.62390
8	14.98275	-10.52679	10.75474
9	13.78582	-10.07581	10.86782
10	11.69458	-9.24796	10.46163
11	10.17231	-9.03573	10.52501
12	8.36348	-8.53023	10.88849
13	14.83112	-10.04854	10.27621
14	13.00124	-9.96621	10.47990
15	11.68145	-9.74277	10.48861
16	17.14909	-10.34392	9.97854
17	15.68133	-10.21090	10.37459
18	14.46805	-9.74277	10.37602

"Larger is better" characteristic has been selected for MRR. The Figure 5 shows the main effects plot for means of S/N ratio for MRR. Table 5 shows response table for S/N ratio for MRR. The best optimum combination obtained from graph and S/N ratio for MRR is A2-B3-C1. The analysis of graphs shows that MRR proportionately increases with increase in pulse on time and decreases with increase in pulse off time. Wire feed rate does not play significant role for MRR. High pulse-on time (TON) results in faster erosion of the material as longer duration of spark results in higher spark energy release hence increase in MRR was observed.

Table 5: Response Table for S/N ratio for MRR

Level	Wire Feed Rate (Wf)	Pulse On Time (Ton)	Pulse Off Time (Toff)
1	12.92	10.42	14.55
2	13	13	12.93
3	----	15.47	11.41
Delta	0.09	5.06	3.14
Rank	3	1	2

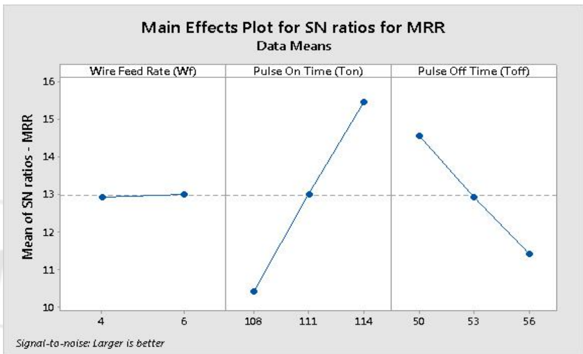

Figure 5: Means of S/N ratio Graph for MRR

ANOVA Table 6 shows that, pulse on time has 71.5% contribution for MRR and pulse off time has 27.8% contribution also, the F-value for pulse on time is maximum (204.84), hence pulse on time has the most significant effect on MRR.

Table 6: ANOVA Table for MRR

Source	DF	Adj. SS	Adj. MS	F - Value	P - Value	% Contr.
Wf	1	0.0477	0.0477	0.94	0.352	0.32704
Ton	2	20.857	10.4287	204.84	0.000	71.5004
Toff	2	8.1164	4.0582	79.71	0.000	27.8235
Error	12	0.6109	0.0509			0.34898
Total	17	29.632	14.5855			

"Smaller is better" characteristics has been selected for SR. The Figure 6 shows the main effects plot for means of S/N ratio for SR. Table 7 shows the response table for S/N ratio for SR. The best optimum combination obtained from graph and S/N ratio for SR is A2-B1-C3. The analysis of graphs shows that SR proportionately increases with increase in pulse on time and decreases with increase in pulse off time and wire feed rate. High pulse-on time (TON) results in faster erosion of the material as longer duration of spark results in higher spark energy release that leads to increase in size of craters formed hence increase in SR was observed.

Table 7: Response Table for S/N ratio for SR

Level	Wire Feed Rate (Wf)	Pulse On Time (Ton)	Pulse Off Time (Toff)
1	-9.985	-9.315	-10.07
2	-9.652	-9.886	-9.852
3	----	-10.255	-9.534
Delta	0.333	0.94	0.536
Rank	3	1	2

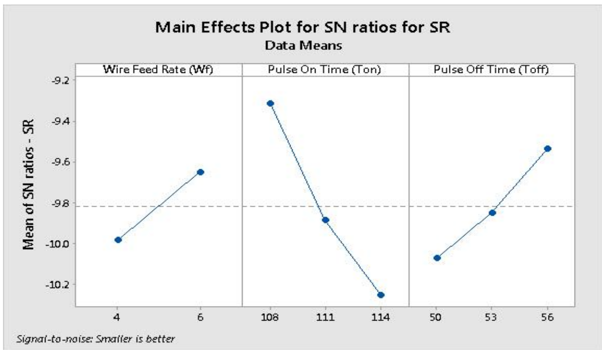

Figure 6: Means of S/N ratio Graph for SR

ANOVA Table 8 shows that, pulse on time has 57.99% contribution for SR and pulse off time has 19% contribution also, the F-value for pulse on time is maximum (28.10), hence pulse on time has most significant effect on SR.

Table 8: ANOVA Table for SR

Source	DF	Adj. SS	Adj. MS	F - Value	P - Value	% Contr.
Wf	1	0.06009	0.06008	10.13	0.008	20.9053
Ton	2	0.33341	0.16671	28.10	0.000	57.9980
Toff	2	0.10941	0.05471	9.22	0.004	19.0325
Error	12	0.07120	0.00593			2.0641
Total	17	0.57411	0.28743			

"Smaller is better" characteristics has been selected for KW. The Figure 7 shows the main effects plot for means of S/N ratio for KW. Table 9 shows the response table for S/N ratio for KW. The best optimum combination obtained from graph and S/N ratio for KW is A1-B2-C3. The analysis of graphs shows that KW proportionately increases with increase in wire feed rate and decreases with increase in pulse off time.

Table 9: Response Table for S/N ratio for KW

Level	Wire Feed Rate (Wf)	Pulse On Time (Ton)	Pulse Off Time (Toff)
1	10.55	10.38	10.29
2	10.43	10.6	10.49
3	----	10.5	10.69
Delta	0.13	0.22	0.4
Rank	3	2	1

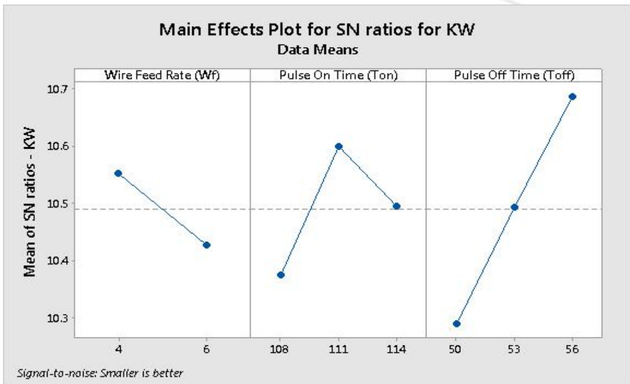

Figure 7: Means of S/N ratio Graph for KW

Confirmation test was conducted by calculating the predicted S/N ratio based on response table for all the three response variables using equation (2).

$$\gamma_{predicted} = \gamma_{mean} + \sum(\gamma_{mean\ optimal} - \gamma_{mean}) \qquad (2)$$

In this γ_{mean} is the total Mean of S/N ratio and γ_{mean} optimal is the value of S/N ratio at optimal Level. Experimental S/N ratio results show an improvement compared to the predicted S/N ratio for all the three response variables.

ANOVA Table 10 shows that, wire feed rate has 67.57% contribution for KW and pulse off time has 18% contribution also, the F-value for wire feed rate is maximum (57.89), hence wire feed rate has most significant effect on KW.

Table 10: ANOVA Table for KW

Source	DF	Adj. SS	Adj. MS	F - Value	P - Value	% Contr.
Wf	1	0.000673	0.000673	57.89	0.000	67.57028
Ton	2	0.000247	0.000123	10.62	0.004	12.34940
Toff	2	0.000375	0.000188	16.13	0.001	18.87550
Error	9	0.000105	0.000012			1.20482
Total	14	0.001209	0.000996			

5. Conclusions

The experimental results for MRR, SR and KW collected during experimentation have been analyzed by using Taguchi method, ANOVA and following conclusion have been drawn.

1. The analysis of graphs and S/N ratios shows that MRR proportionately increases with increase in pulse on time and decreases with increase in pulse off time. Wire feed rate does not play significant role for MRR.
2. ANOVA for MRR shows that, pulse on time has 71.5% contribution for MRR and pulse off time has 27.8% contribution also, the F-value for pulse on time is maximum (204.84), hence pulse on time has most significant effect on MRR.
3. The analysis of graphs and S/N ratios shows that SR proportionately increases with increase in pulse on time and decreases with increase in pulse off time and wire feed rate.
4. ANOVA for SR shows that, pulse on time has 57.99% contribution for SR and pulse off time has 19% contribution also, the F-value for pulse on time is maximum (28.10), hence pulse on time has most significant effect on SR.
5. High pulse-on time (TON) results in faster erosion of the material as longer duration of spark results in higher spark energy release that leads to increase in size of craters formed hence increase in MRR and SR was observed.
6. The analysis of graphs and S/N ratio shows that KW proportionately increases with increase in wire feed rate and decreases with increase in pulse off time.
7. ANOVA for KW shows that, wire feed rate has 67.57% contribution for KW and pulse off time has 18% contribution also, the F-value for wire feed rate is maximum (57.89), hence wire feed rate has most significant effect on KW.

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