PARAMETRIC STUDY AND OPTIMISATION OF PROCESS PARAMETERS OF WEDM FOR D2 STEEL

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ABSTRACT: *In modern technology, manufacturers try to ascertain control factors to improve the machining quality based on their operational experiences, manuals or failed attempts. Keeping in view my Experimental research has been carried out to investigate and optimize the process parameters of Wire EDM for D2 steel. D2 Die steel is an air hardening, high carbon, and High chromium tool steel. In this study, all experiment is tested using EZECUT PLUS WIRE EDM (RRAPT), available at IDTR Jamshedpur. Input process parameters that are taken into consideration are Wire feed rate, Pulse on time, Pulse off time, Peak current, and Servo voltage. Output parameters are Material removal rate, Kerf width, Surface roughness. We used Taguchi methodology of L18 orthogonal array for design of experiment. Here we selected Grey relational analysis for optimization. From the experiment, it can be conclude that Pulse on time is the greatest effect on MRR and surface roughness compare to other parameters. Servo voltage has little effect on SR and kerf width but it has more effect over MRR. The study demonstrates that the WEDM process parameters can be optimised so as to achieve higher MRR with better surface finish and kerf width.*

INDEX TERMS: *Wire EDM, ANOVA, D2 steel, Taguchi, MRR, Surface roughness, kerf width, grey relational theory, MINITAB 15.*

I. INTRODUCTION

1.1 NON CONVENTIONAL MACHINING:

In modern manufacturing industries, Non-conventional machining processes are widely used for machining hard materials. Nonconventional machining processes are classified according to the machining action which helps in material removal from the work piece. These methods are generally more expensive to set up, have a slower rate of metal removal and require considerable technical know-how. One of the most widely used Non-Conventional Machining process in industry is Electrical Discharge Machining (EDM). Electric Discharge Machining is based on the principle of removing material by means of repeated electrical discharges between the tool termed as electrode and the work piece in the presence of a dielectric fluid. .[SHAN & PANDEY]

1.2 WIRE EDM:

Wire Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. It uses a wire as the electrode. The wire is stretched out and then submerged in deionized water along with the work piece(fig1.2). The water acts as dialectic until the electric discharge happens. As the wire moves toward the material to cut and the distance gets smaller, the voltage increases and a spark is created between the wire and the material. The heat caused by this electric discharge enables the wire to cut through the material.[P C SHARMA]

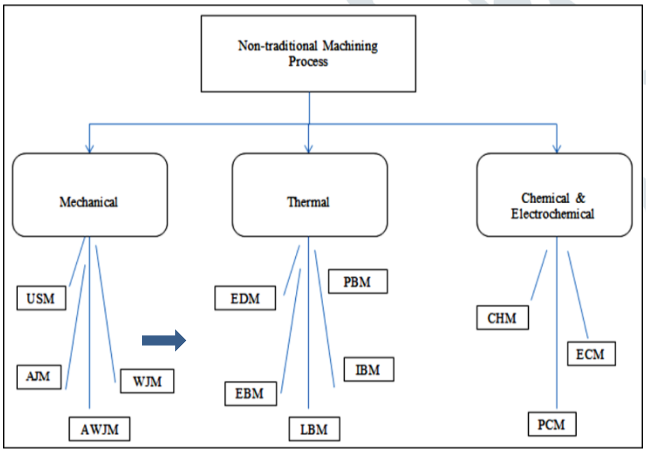

Fig1.1: Non-conventional machining process

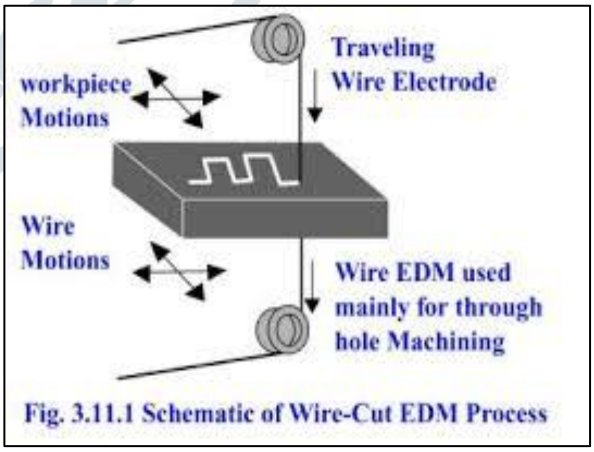

Figure 1.2: Working principle of wire-cut EDM

1.3 ADVANTAGE OF WIRE EDM:

- ❖ Wire cut EDM gives efficient production capabilities through high precision and high-speed.
- ❖ During machining, the work piece is not subjected to mechanical deformation as there is no physical contact between the tool and work.
- ❖ It eliminates additional finishing processes such as sanding or grinding.
- ❖ Wire EDM is non-contact and force free. Thus it eliminates cutting stress and mechanical distortion.
- ❖ Materials cut with Wire EDM are totally burr-free, the edges are perfectly straight.

1.4 OBJECTIVE OF PROJECT:

We founded a lot of gap for process parameters of WEDM for D2 steel work piece in a literature survey. Thus we determined the following objective:

- To study the effect of process parameters vs output parameters of Wire cut EDM for D2 STEEL Material.
- Investigation of the working ranges and levels of the Wire cut EDM process parameters using five factor at a time approach.
- With the help of ANOVA, analyses the output parameters MRR ,Surface roughness and Kerf width.
- To find the optimum levels/ ranges of input parameters to get optimum output parameters using Grey relational method.

II. EXPERIMENTAL PROCEDURE

2.1 PROCESS PARAMETERS SELECTION:

2.1.1 Input Parameters with levels value:

Table:2.1 Input parameter with three level:

Sr. no.	PARAMETER	LEVEL 1	LEVEL2	LEVEL3
1	WFR(m/min)	6	8	-
2	PON(μs)	110	115	120
3	POFF(μs)	50	55	60
4	Ip(amp)	120	140	160
5	SV(volt)	15	20	25

2.1.2 Fixed factors:

Table:2.2 Input parameter with fixed value:

Sr. no.	Fixed parameters	Set value
1.	Wire material	brass(0.25mm)
2.	Wire electrode	D2 steel
3.	Flushing pressure	1.2 kgf/cm^2
4.	Die-electric fluid	EDM oil

2.2 EXPERIMENTAL SET-UP:

2.2.1 Wire-cut EDM set-up:

The experimental setup and the experiment is designed and carried out on EZECUT Plus Wire-cut EDM (RRAPT) which is placed at IDTR Jamshedpur. EZECUT Plus Wire-cut EDM consists of a coordinate worktable, wire running system, wire frame, Microcomputer based control cabinet and dielectric supply system.

Figure 2.1 Wire cut EDM (at IDTR Jamshedpur)

Figure 2.2 WEDM CNC cabinet

Table 4.1 Wire cut machine specification:

EZECUT PLUS WEDM	
Max. work piece size	360 x 600 mm
Max. z height	400 mm
Max. work piece wt.	300 kg
Mini table traverse (X,Y)	320,400mm
Auxiliary table traverse(u,v)	25, 25mm
Machine tool size (L*W*H)	1500 x 1250 x 1700
Max. taper cutting angle	± 3º/100mm
Machine tool weight	1400 kg
Max dry run speed	25 mm/min
Best surface finish	1-1.5μm
Wire diameter	0.20-0.25mm(brass)
PULSE GENERATOR	
Pulse generator	EZECUT-40 A DLX
Pulse peak voltage	1 Step
CNC controller	EMT 100W-5
Input power supply	8.3 phase, AC, 415, 50Hz
Connected load	10 Kva
Average power consumption	6 -7 Kva
DIELECTRIC FLUID	

Tank capacity	200 liters
Die-electric Fluid type	Non-conductive oil

2.2.2 Selection of work piece:

Here we have taken D2 die steel. D2 Die steel is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties. It is heat treatable and will offer hardness in the range 56-63 HRC, and is machinable in the annealed condition. D2 steel is recommended for tools requiring very high wear resistance, combined with moderate toughness like Punches, Dies, Forming rolls etc.

Table:2.3 Chemical composition of D2 steel:

C	Si	Cr	Mo	V
1.50%	0.30%	12.00%	0.80%	0.90%

2.2.3 Selection of electrode material:

In this project work we used Brass wire as electrode. This wire is a combination of copper and zinc, typically alloyed in the range of 63– 65% Cu and 35–37% Zn. The addition of zinc provides significantly higher tensile strength, a lower melting point and higher vapor pressure rating, which more than offsets the relative losses in conductivity.

Table:2.4 composition of electrode wire:

Material	Tensile strength	Breaking load	Wire dia.
Brass wire	980N/mm^2	4.92 kg	0.25mm

2.3 MACHINING CHARACTERISTIC:

In this dissertation work, we have taken only three characteristic measures which are discussed below.

2.3.1 Material Removal Rate:

MRR determines economics of machining and rate of production. In this process, cutting speed is an important factor.

Based on Volume method

MRR= Cutting Speed (mm/min) x Thickness of w/p (mm) ………..Eq.(2.1) .[8,9]

2.3.2 Surface Roughness:

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Surface roughness of the piece that is cut from the work piece plate is measured using a surface roughness TESTER TR110 found at IDTR Jamshedpur.

Fig: 2.2 surface roughness TR110

Table: 2.5 Specification of TR110:

Model	TR110
Roughness parameter	Ra, Rz
Measuring range	Ra: 0.05-10.0µ Rz:0.1-50µ
Evaluation length	1.25mm/4.0mm/5.0mm
Cut-off lengths	0.25mm/0.8mm/2.5mm
Tracing speed	1.0mm/sec
Tracing length	6mm
Accuracy	±15%
Radius and angle of the stylus point	Diamond Radius : 10±2.5µ, Angle: 90°(+5°or -10°)
Pick-up	Piezoelectric
Filter	RC analogue
Repeatability	<12%
Operating temperature	0-40 ℃
Power supply	3.6V Li-ion battery
Storing temperature	-25 ℃ -60 ℃
Relative humidity	<80%

2.3.3 Kerf width:

It is denoted by KW. The amount of the material that is wasted during machining is measured as KW. It determines the dimensional accuracy of the finishing part. DYNAVERT profile projector as shown in Fig. below available at IDTR JAMSHEDPUR. The least count of this optical profile projector is 0.005mm.

fig 2.3:Profile projector (at IDTR Jamshedpur)

Table:2.6 DYNAVERT Profile projector specification:

Magnification	Accuracy of Magnification	X-Y-Z Displacement	Electrical requirement	Light source
10x -500x	Within ±0.1% of nominal value of each lens Within ±0.15% when used half reflecting mirror	82 x 62 x 74	Primary current A.C 100V Single phase 50-60 cycle Capacity 150V	70W with specified filament
Optional Accessories: Inclinable canters, V block, Holder with clamp, Pedestal stand geometric data processor quadra check qc 221.				

2.4 EXPERIMENTAL DESIGN:

In Engineering Design work, Design of experiment (DOE) is effective tool to investigate the process or the product variables that influence the product quality. It is an efficient procedure for planning experiments so that obtained data can be analyzed to yield valid and objective conclusions. DOE begins with determining the objectives of an experiment and selecting the process factors for the study. In this thesis, we are using Taguchi method. As per table, L18 orthogonal array of "Taguchi method" has been selected for the experiments design in Software MINITAB 15'

Each time we performed an experiment with particular set of parameter combination and work piece is cut as per figure 2.4. In the present study, the job has been considered as a square punch. Table 2.7 summarizes the results obtained for 18 runs. The work material in the form of square plate having dimensions 148 mm × 148 mm × 16 mm was taken for the experimentation work and specimens of 6mm x 6mm x16mm size are cut.

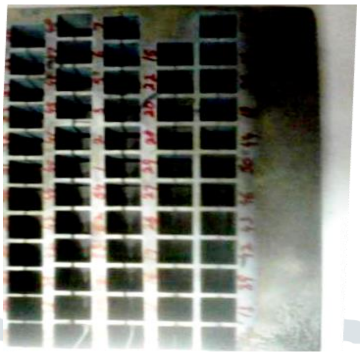

fig 2.4(c) cutted specimen

Fig2.4(a) wire path profile during machining ; Fig 2.4(b) work piece after machining

TABLE:2.7 Final result data **(**Orthogonal Array L18**)**

Sr. no.	WF (m/min)	Ton (µs)	Toff (µs)	IP (Amp)	SV (volt)	MRR (mm^2/min)	KW (mm)	SR (µm)
1	6	110	50	120	15	15.203	0.2908	2.5569
2	6	110	55	140	20	14.901	0.2989	2.5011
3	6	110	60	160	25	08.921	0.3102	2.4235
4	6	115	50	120	20	23.766	0.3086	2.8834
5	6	115	55	140	25	19.801	0.3179	3.1024
6	6	115	60	160	15	21.141	0.2788	3.2561
7	6	120	50	140	15	28.916	0.3385	3.7236
8	6	120	55	160	20	29.803	0.3028	3.3842
9	6	120	60	120	25	20.084	0.2739	2.8923
10	8	110	50	160	25	18.802	0.2633	2.3908
11	8	110	55	120	15	16.901	0.1934	2.4198
12	8	110	60	140	20	14.204	0.2031	2.1600
13	8	115	50	140	25	25.205	0.2897	2.9785
14	8	115	55	160	15	26.844	0.2332	3.4236
15	8	115	60	120	20	18.001	0.1989	2.6039
16	8	120	50	160	20	31.604	0.3310	3.5139
17	8	120	55	120	25	29.102	0.2697	3.0667
18	8	120	60	140	15	27.600	0.2381	3.1522

III. ANOVA ANALYSIS

3.1 S/N RATIO:

It is applied to the results of the experiment to determine the percent contribution of each factor. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not.

TABLE:3.1 Responses and S/N Ratio:

Sr. no.	MRR (mm^2/min)	KERF (mm)	SR (µm)	MRR(S/N) (mm^2/min)	KERF(S/N) (mm)	SR (S/N) (µm)
1	15.203	0.2908	2.5569	23.6369	10.7281	-8.1543
2	14.901	0.2989	2.5011	23.4637	10.4895	-7.9626
3	08.921	0.3102	2.4235	19.0073	10.1672	-7.6889
4	23.766	0.3086	2.8834	27.5169	10.2121	-9.1981
5	19.801	0.3179	3.1024	25.9333	9.9542	-9.8340
6	21.141	0.2788	3.2561	26.5021	11.0941	-10.2540
7	28.916	0.3385	3.7236	29.2210	9.4088	-11.4193
8	29.803	0.3028	3.3842	29.4843	10.3769	-10.5891
9	20.084	0.2739	2.8923	26.0553	11.2482	-9.2249

10	18.802	0.2633	2.3908	25.4832	11.5910	-7.5709
11	16.901	0.1934	2.4198	24.5577	14.2709	-7.6756
12	14.204	0.2031	2.1600	23.0458	13.8458	-6.6891
13	25.205	0.2897	2.9785	28.0280	10.7610	-9.4800
14	26.844	0.2332	3.4236	28.5757	12.6454	-10.6897
15	18.001	0.1989	2.6039	25.1055	14.0273	-8.3125
16	31.604	0.3310	3.5139	29.9937	9.6034	-10.9158
17	29.102	0.2697	3.0667	29.2779	11.3824	-9.7334
18	27.600	0.2381	3.1522	28.8182	12.4648	-9.9723

3.2 RESPONSE TABLE:

Below table show the response Table of MRR, KW and SR for Brass wire electrode and D2 steel work piece. Delta shows the difference between maximum value and minimum value. Each level for particular factor shows the mean value, and highest values to be choose as optimize value.

3.2.1Signal to Noise Ratio for MRR:

Table3.2: Response Table for Signal to Noise Ratios

Larger is better

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	25.65	23.20	27.31	26.03	26.89
2	26.99	26.94	26.88	26.42	26.43
3	-	28.81	24.76	26.51	25.63
Delta	1.34	5.61	2.56	0.48	1.25
Rank	3	1	2	5	4

Table3.3: Response Table for Means

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	20.28	14.82	23.91	20.51	22.77
2	23.14	22.46	22.89	21.77	22.04
3	-	27.85	18.32	22.85	20.32
Delta	2.86	13.03	5.59	2.34	2.45
Rank	3	1	2	5	4

From the above Table optimal level combination factor for MRR is 8m/min(level 2) for Wire feed, 120 µs(level 3) for Ton, 50 µs(level1) for Toff, 160 Amp(level 3) for Peak Current and 15 V(level 1) for Servo Voltage.

3.2.2 Signal to Noise Ratio for Kerf Width:

Table3.4: Response Table for Signal to Noise Ratios

Smaller is better

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	10.41	11.85	10.38	11.98	11.17
2	12.29	11.45	11.52	11.15	11.43
3	-	10.75	12.14	10.91	10.85
Delta	1.88	1.10	1.76	1.07	0.92
Rank	1	3	2	4	5

Table3.5: Response Table for Means

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	0.3023	0.2599	0.3037	0.2559	0.2621
2	0.2467	0.2712	0.2693	0.2810	0.2739
3	-	0.2923	0.2505	0.2866	0.2874
Delta	0.0556	0.0324	0.0532	0.0307	0.0253
Rank	1	3	2	4	5

From the above Table optimal level combination factor for Kerf Width is 8m/min (level 2)for Wire feed, 110 µs(level 1) for Ton, 60 µs(level 3) for Toff, 120 Amp (level 1)for Peak Current and 15V(level 1) for Servo Voltage.

3.2.3 Signal to Noise Ratio for Surface Roughness:

Table3.6: Response Table for Signal to Noise Ratios

Smaller is better

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	-9.369	-7.624	-9.456	-8.716	-9.694
2	-9.004	-9.628	-9.414	-9.226	-8.945
3		-10.309	-8.690	-9.618	-8.922
Delta	0.365	2.686	0.766	0.902	0.722
Rank	5	1	3	2	4

Table3.7: Response Table for Means

Level	WF(m/min)	Ton(µs)	Toff(µs)	Ip(amp)	SV(volt)
1	2.969	2.090	3.008	2.737	3.089
2	2.857	3.041	2.983	2.936	2.841
3	-	3.289	2.748	3.065	2.809
Delta	0.113	0.880	0.260	0.328	0.280
Rank	5	1	4	2	3

From the above Table optimal level combination factor for Surface Roughness is 8m/min (level 2)for Wire feed, 110 µs (level 1) for Ton, 60 µs (level 3) for Toff, 120 Amp(level 1) for Peak Current and 25 V(level 3) for Servo Voltage.

3.3 ANOVA FOR MRR:

Table3.8: ANOVA for MRR

SOURCE	DF	Seq. SS	Adj SS	Adj MS	F	P
WF(m/min)	1	36.780	36.780	36.780	19.54	0.002
Ton(µs)	2	514.252	514.252	257.126	136.62	0.000
Toff(µs)	2	106.255	106.255	53.128	28.23	0.000
Ip(Amp)	2	16.506	16.506	8.253	4.39	0.052
Sv(Volt)	2	18.993	18.993	9.497	5.05	0.038
Error	8	15.056	15.056	1.882		
Total	17	707.842				
DF - degrees of freedom, SS - sum of squares, MS – mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level						

- Calculation of SS' and Percentage Contribution of MRR:
- Pure sum of square (SS):
  For WF: SS= 36.780 – (1*1.882)= 34.898
  For Ton: SS= 514.252 – (2*1.882)=510.488
  For Toff: SS= 106.255 – (2*1.882) =102.491
  For IP: SS= 16.506 – (2*1.882)= 12.742
  For SV: SS= 18.993 – (2*1.882)= 15.229
- Percentage contribution:
  For WF: P= (34.898/707.842)* 100 = 4.93%
  For Ton: P= (510.488/707.842)* 100= 72.12%
  For Toff: P= (102.491/707.842)* 100 =14.48%
  For IP: P= (12.742/707.842)* 100 =1.80%
  For SV: P= (15.229/707.842)* 100 =2.15%

Above results describe the percentage contribution of individual process input parameters of WEDM on D2 steel for Material removal rate. The percentage contribution of Wire feed rate is 4.93%, Ton is 72.12%, Toff is 14.48%, Peak current is 1.80%, Servo voltage is 2.15%, and error is 4.52%. This error is due to machine vibration.

3.4 ANOVA FOR KERF WIDTH:

Table3.9:ANOVA for KW

SOURCE	DF	Seq. SS	Adj SS	Adj MS	F	P
WF(m/min)	1	0.0138889	0.0138889	0.0138889	35.74	0.000
Ton(µs)	2	0.0032444	0.0032444	0.0016222	4.17	0.057
Toff(µs)	2	0.0087155	0.0087155	0.0043578	11.21	0.005
Ip(Amp)	2	0.0032068	0.0032068	0.0016034	4.13	0.059
Sv(Volt)	2	0.0019261	0.0019261	0.0009631	2.48	0.145
Error	8	0.0031089	0.0031089	0.0003886		
Total	17	0.0340906				
DF - degrees of freedom, SS - sum of squares, MS – mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level						

- Calculation of SS' and Percentage Contribution of KERF WIDTH:
- Pure sum of square (SS):
  For WF: SS= 0.0138889 – (1*0.0003886) =0.013500
  For Ton: SS= 0.0032444 – (2*0.0003886) = 0.002467
  For Toff: SS= 0.0087155 – (2*0.0003886) =0.007938
  For Ip: SS= 0.0032068 – (2*0.0003886) =0.0024296
  For sv: SS= 0.0019261 – (2*0.0003886) =0.0011489
- Percentage contribution:
  For WF: P= 0.013500/0.0340906* 100=39.60%
  For Ton: P= 0.002467/0.0340906* 100=7.23%
  For Toff: P= 0.007938/0.0340906* 100= 23.29%
  For IP: P= 0.002467/0.0340906* 100= 7.13%
  For SV: P= 0.0011489/0.0340906* 100= 3.37%

Above results describe the percentage contribution of individual process input parameters of WEDM on D2 steel for Kerf Width. The percentage contribution of Wire feed rate is 39.60%, Ton is 7.23%, Toff is 23.29%, Peak current is 7.13%, Servo voltage is 3.37%, and error is 19.38%. This error is due to machine vibration.

3.5 ANOVA FOR SURFACE ROUGHNESS:

Table5.10:ANOVA for SR

SOURCE	DF	Seq. SS	Adj SS	Adj MS	F	P
WF(m/min)	1	0.05713	0.05713	0.05713	6.50	0.034
Ton(μs)	2	2.47223	2.47223	1.23612	140.69	0.000
Toff(μs)	2	0.24670	0.24670	0.12335	14.04	0.002
Ip(Amp)	2	0.32802	0.32802	0.16401	18.67	0.001
Sv(Volt)	2	0.28111	0.28111	0.14055	16.00	0.002
Error	8	0.07029	0.07029	0.00879		
Total	17	3.45549				
DF - degrees of freedom, SS - sum of squares, MS – mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level						

- Calculation of SS' and Percentage Contribution of surface roughness :
- Pure sum of square (SS):
  For WF: SS= 0.05713 – (1*0.00879) =0.04834
  For Ton: SS=2.47223 – (2*0.00879) = 2.45465
  For Toff: SS= 0.24670 – (2*0.00879) = 0.22912
  For Ip: SS= 0.32802 – (2*0.00879) = 0.31044
  For Sv: SS= 0.28111 – (2*0.00879) = 0.26353
- Percentage contribution:
  For WF: P= 0.04834/3.45549* 100=1.40%
  For Ton: P= 2.45465/3.45549* 100=71.04 %
  For Toff: P= 0.22912/3.45549* 100= 6.63%
  For IP: P= 0.31044/3.45549* 100= 8.98%
  For SV: P=0.26353/3.45549* 100=7.63%

Above results describe the percentage contribution of individual process input parameters of WEDM on D2 steel for Surface Roughness. The percentage contribution of Wire feed rate is 1.40%, Ton is 71.04%, Toff is 6.63%, Peak current is 8.98%, Servo voltage is 7.63%, and error is 4.32%. This error is due to machine vibration.

IV. OPTIMISATION BY GREY RELATIONAL THEORY

4.1 CALCULATION OF GREY RELATIONAL COEFFICIENT & GREY RELATIONAL GRADE:

A grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. After obtaining the Grey relation coefficient, its average is calculated to obtain the Grey relation grade. Grey relational grade value reflects the single optimization value of the multiple experimental output or performance.

The Grey relation coefficient can be express as follows.

$$\zeta_i(k) = (\Delta \min + \psi \Delta \max) \div (\Delta_{0i}(k) + \psi \Delta \max) \text{ ……..Eq.(4.1)}$$

Where, $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_{i(k)}$ and the comparability sequence.

ζ is distinguishing or identification coefficient.

$\zeta \in (0,1)$ is generally used.

And, ψ = distinguishing or identification coefficient in between zero and one.

Grey relational coefficient is calculated by selecting proper distinguishing coefficient. Here $\psi = 0.5$ is selected.

$$\Delta_{0i} = \left| x_0(k) - x_i(k) \right| \text{ ………..Eq.(4.2)}$$

$$\Delta_{\min} = \min_{\forall (i \in I)} \min_{\forall k} \left| x_0(k) - x_i(k) \right| \text{ ……….Eq.(4.3)}$$

$$\Delta_{\max} = \max_{\forall (i \in I)} \max_{\forall k} \left| x_0(k) - x_i(k) \right| \text{ …….Eq.(4.4)}$$

$$\gamma_i = 1/n \sum_{k=n}^{n} \zeta i(k) \text{ …………Eq.(4.5)}$$

However, In real application the effect of each factor on the system is not exactly same, Eq.4.5 can be modified as:

$$\gamma_i = 1/n \sum_{k=n}^{n} W_k \, \zeta i(k) \text{ ……….Eq.(4.6)}$$

Where, W_K represents the normalized weighting value of factor k.

In this research work, normalization of material removal rate, surface roughness and kerf width is done between 0 and 1. Here for material removal rate larger-the-better, and for kerf width and surface roughness normalization equation smaller-the-better is used.[8, 9, 21]

Table 4.1: Grey relational coefficients and Grades

EXP. NO	Grey relation coefficients			Grey relational Grade	Orders
	MRR	KW	SR		
1	0.4088	0.4269	0.6633	0.4997	12
2	0.4044	0.4074	0.6962	0.5027	11
3	0.3333	0.3831	0.7479	0.4881	16
4	0.5912	0.3864	0.5194	0.4990	13
5	0.4901	0.3682	0.4534	0.4372	18

6	0.5202	0.4593	0.4163	0.4653	17
7	0.8083	0.3333	0.3333	0.4916	15
8	0.8630	0.3987	0.3897	0.5505	9
9	0.4961	0.4740	0.5163	0.4955	14
10	0.4698	0.5093	0.7721	0.5837	6
11	0.4355	1.0000	0.7506	0.7287	2
12	0.3946	0.8821	1.0000	0.7589	1
13	0.6392	0.4297	0.4885	0.5191	10
14	0.7043	0.6458	0.3822	0.5774	7
15	0.4547	0.9295	0.6378	0.6740	3
16	1.0000	0.3452	0.3661	0.5704	8
17	0.8194	0.4874	0.4630	0.5899	5
18	0.7392	0.6188	0.4407	0.5996	4

Now it is clearly observed from above table 4.1 that the wire cut EDM process parameters setting of experiment no. 12 has the highest grey relation grade. Thus, the twelve experiments gives the best multi-performance characteristics among the 18 experiments.

Table 4.2: Average grey relational grade:

Parameters	Average Grey relational grade by Factor level		
	Level 1	level 2	level 3
Wire feed rate A	0.4922	**0.6224**(8m/min)*	-
Pulse on time B	**0.5936**(110 μs)*	0.5287	0.5496
Pulse off time C	0.5273	0.5644	**0.5802**(60μs)*
Peak current D	**0.5811**(120Amp)*	0.5515	0.5392
Servo voltage E	0.5604	**0.5926**(20 volt)*	0.5189

Above table 4.2 shows optimum parameter levels which are indicated by star symbol(*). In this table, higher grey relational grade from each level of factor indicates the optimum level. From this table it is concluded that the optimum parameter level for Wire feed rate, Pulse on time, Pulse off time, Peak current, Servo voltage is (8 m/min), (110 μs), (60 μs), (120 Amp), (20 volt) respectively.

4.2 ANALYSIS OF GREY RELATIONAL GRADE:

In below graph (fig 4.1), 12th experiment gives the best multi- performance characteristics of the WEDM process among the18experiment.

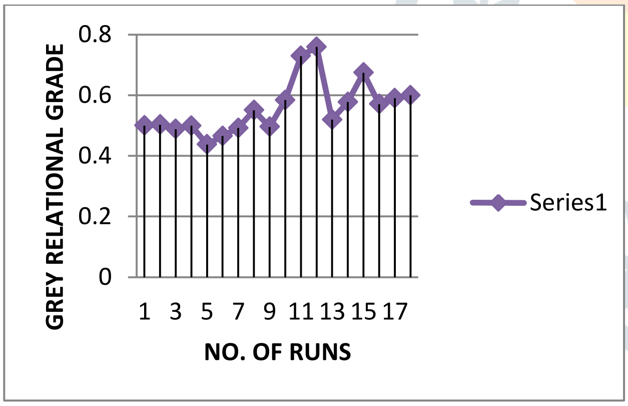

Fig4.1: Graph of grey relational grade

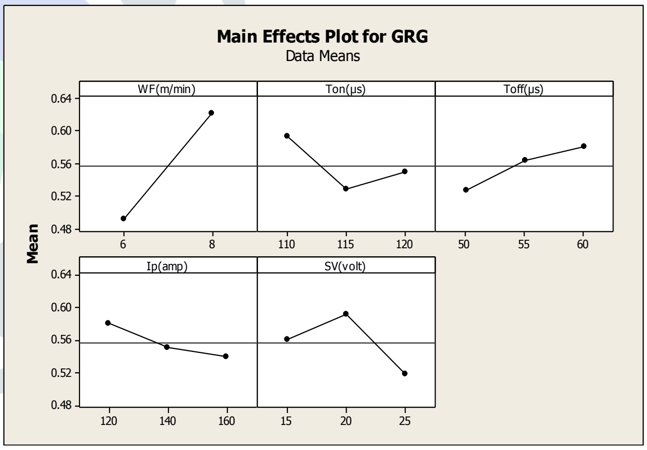

Fig4.2: Mean effects plot for GRG

4.3 CONFIRMATION TEST:

Confirmation test is the final step in the experiment. It is used to validate the conclusion drawn during the analysis phases. Also, the confirmation tests need to be carried out in order to ensure that the theoretical predicted parameter combination for optimum results using the software is acceptable or not. The parameters used in the confirmation test are suggested by grey relational analysis. The confirmation test with optimal process parameters is performed on Wire cut EDM of D2 steel work piece at levels A2 (8m/min wire feed rate), B1 (110 μs Pulse on time), C3 (60 μs Pulse off time), D1 (120 Amp Peak current), E2 (20 volts Servo voltage) and it gives material removal rate 13.8 mm2/min , kerf width of 0.1907 mm, and surface roughness of 2.04 μm.

The error found in material removal rate is 2.89% ,in kerf width is 6.50% and in surface roughness is 5.88%. In this chapter, we have done grey relational analysis based optimization of Wire cut EDM process parameters for D2 steel .Higher grey relational grade gives better multi performance characteristics and from the table of average grey relational grade, optimum parameter levels are obtained.

V. RESULTS AND DISCUSSION

Below figure shows the relation between all variable parameters like wire feed rate, pulse on time, pulse off time, peak current and servo voltage for MRR(fig 5.1) ,kerf width (fig 5.2)and Surface Roughness(fig 5.3) respectively.

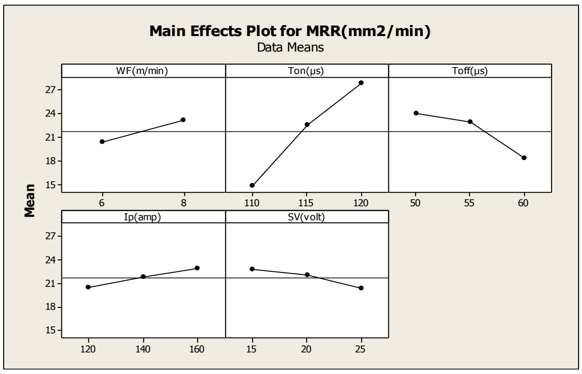

Fig: 5.1: main effects plot for MRR

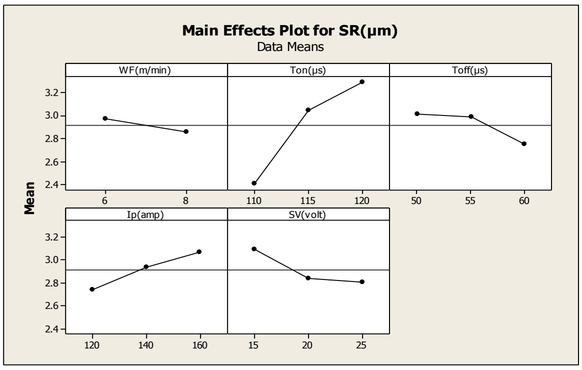

Fig:5.3: main effects plot for SR

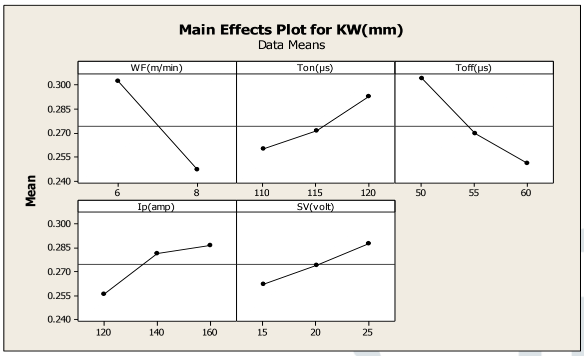

Fig:5.2 main effects plot for KW

For Material Removal Rate, ANOVA analysis result gives percentage contribution of wire feed 4.93%, pulse on time is 72.12%, pulse off time 14.48%, peak current is 1.80%, and servo voltage is 2.15%. For the MRR the rank and the delta values for various parameters show that pulse on time is the greatest effects on MRR and is followed by pulse off time, wire feed, servo voltage, and peak current in that order. The optimal level combination factor for MRR is 8m/min for Wire feed, 120 µs for Pulse on time, 50 µs for Pulse off time, 160 Amp for Peak Current and 15 V for Servo Voltage.

For kerf width, ANOVA analysis result gives the percentage contribution of wire feed 39.60%, pulse on time is 7.23%, pulse off time 23.29%, peak current is 7.13%, and servo voltage is 3.37%. For the kerf width, the rank and the delta values for various parameters show that wire feed is the greatest effects on kerf width and is followed by pulse off time, pulse on time, peak current, and servo voltage in that order. The optimal level combination factor for kerf width in D2steel is 8m/min for Wire feed, 110 µs for Pulse on time, 60 µs for Pulse off time, 120 Amp for Peak current and 15 V for Servo Voltage.

For Surface roughness, ANOVA analysis result gives the percentage contribution of wire feed 1.40%, pulse on time is 71.04%, pulse off time 6.63%, peak current is 8.98%, and servo voltage is 7.63%. For the Surface roughness, the rank and the delta values for various parameters show that pulse on time is the greatest effects on surface roughness and is followed by peak current, servo voltage, pulse off time, and wire feed in that order. The optimal level combination factor for surface roughness in D2 steel is 8m/min for Wire feed, 110 µs for Pulse on time, 60 µs for Pulse off time, 120 Amp for Peak Current and 25 V for Servo Voltage.

Also, we have done Grey relational analysis to find out optimal parameters levels. After grey relational analysis for D2 steel, it is found that optimum parameter level for Wire feed rate, Pulse on time, Pulse off time, Peak current, Servo voltage is (8 m/min), (110 µs), (60 µs), (120 Amp), (20 volt) respectively. And the results of optimum parameters are Material removal rate is gives material removal rate 13.8 mm^2/min, kerf width of 0.1907 mm, and surface roughness of 2.04 µm.

VI. CONCLUSION

From the results, we concluded that pulse on time is the greatest effect on MRR and surface roughness compare to other parameters in D2 steel. Kerf width is largely affect by wire feed rate. at higher pulse off time, less number of discharges in a given time during machining and results in small MRR, and Kerf width. Servo voltage has little effect on SR and kerf width but it has more effect over MRR. Material removal rate, Kerf width and surface roughness increase with increase in peak current and pulse-on time and vice-versa.

VII. FUTURE SCOPE

- The mathematical model can be developed with different work piece and electrode materials for Wire cut EDM processes.
- Responses like roundness, circularity, cylindricity, machining cost etc. are to be considered in further research.
- The standard optimization procedure can be developed and the optimal results are to be validated with different Multi criteria decision making method.
- Further study can be explored in direction of comparison of Wire cut EDM with other non-conventional methods.

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