Experimental Analysis and Optimization of Parameters in Electric Discharge Machining of Titanium Alloy using Graphite Electrode

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Abstract – With the increasing demands of high surface finish and machining of complex shape geometries, conventional machining process are now being replaced by non-traditional machining processes. The high temperature gradients generated at the gap during electrical discharge machining (EDM) result in large localized thermal stresses in a small heat-affected zone. These thermal stresses can lead to micro-cracks, decrease in strength and fatigue life and possibly catastrophic failure. In this investigation were conducted based on different parameters and various methods used by other to estimate the Surface finish ,Machining timing and material removal rate on work material of Titanium grade 3. The experiments were carried out as per L9 orthogonal array. Each experiment was performed under different conditions such as Ampere rating, pulse on time and pulse off time. The optimal factor for Surface Roughness obtained when Pulse on time is 8µs, Pulse Off time 8 µs and Amps-14. Minimum machining timing obtained when Pulse on time is 7µs, Pulse Off time 10 µs and Amps-12 and Material Removal rate were obtained when Pulse on time is 8µs, Pulse Off time 10 µs and Amps-10. Surface Roughness property mostly influenced with -pulse off time 71%, Machining Timing mostly influenced with 52% pulse on time and Material Removal Rate mostly influenced with 53%. Pulse on time.

Index Terms – Geometries, EDM, Thermal, Micro-cracks.

1. INTRODUCTION

1.1 Electric Discharge Machining

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest.

After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece. Thus, a replica of the tool surface shape is formed on the work piece as shown in Figure 1.1. If the tool is held 3 stationary, machining would stop at this stage. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed. The tool is fed until the required depth of cut is achieved. Finally, a cavity corresponding to replica of the tool shape is formed on the work piece.

2. LITERATURE REVIEW

Shailesh Dewangan[1] et.al were analyzed Surface integrity remains one of the major areas of concern in electric discharge machining (EDM).During the current study, grey-fuzzy logic-based hybrid optimization technique is utilized to determine the optimal settings of EDM process parameters with an aim to improve surface integrity aspects after EDM of AISI P20 tool steel. The experiment is designed using response surface methodology (RSM)considering discharge current (Ip), pulse-on time (Ton), tool-work time (Tw) and tool-lift time (Tup) asprocess parameters. Various surface integrity characteristics such as white layer thickness (WLT), surfacecrack density (SCD) and surface roughness (SR) are considered during the current research work. Grey relational analysis (GRA) combined with fuzzy-logic is used to determine grey fuzzy reasoning grade (GFRG). The optimal solution based on this analysis is found to be Ip ¼ 1 A, Ton ¼ 10 ms, Tw ¼ 0.2 s, and Tup ¼ 0.0 s. Analysis of variance (ANOVA) results clearly indicate that Ton is the most contributing parameter followed by Ip, for multiple performance characteristics of surface integrity.

Milan Kumar Das[2] were investigated combination of process parameters for optimum surface roughness and material removal rate (MRR) in electro discharge machining (EDM) of EN31 tool steel using artificial bee colony (ABC) algorithm. Forexperimentation, machining parameters viz., pulse on time, pulse off time, discharge current and voltage are varied based on central composite design (CCD). Second order response equations for MRR and surface roughness are found out using response surface methodology (RSM). For optimization, both single and multi-objective responses (MRR and surface roughness: Ra) are considered. From ABC analysis, the optimum combinations of process parameters are obtained and corresponding values of maximum MRR and minimum Ra are found out. Confirmation tests are carried out to validate the analyses and it is seen that the predicated values show good agreement with the experimental results. This study also investigates the influence of the machining parameters on machining performances. It is seen that with an increase in current and pulse on time, MRR and surface roughness increase in the experimental regime. Finally, surface morphology of machined surfaces is studied using scanning electron microscope (SEM) images.

M.Dastagiri[3] were experimentally analyzed pursue the influence of four design factors current (I), voltage (V), pulse on(Ton), and duty factor (η) which are the most connected parameters to be controlled by the EDM process over machining specifications such as material removal rate (MRR) and tool wear rate(TWR) and characteristics of surface integrity such as average surface roughness (Ra) and the hardness (HR) and also to quantify them. In this paper the experiments have been conducted by using full factorial design 23 with three central point in the DOE techniques and developed a mathematical model to predict material removal rate, average surface roughness and hardness using input parameters such as current, voltage, pulse on, and duty factor. The predicted results are very close to experimental values. Hence this mathematical model could be used to predict the responses such as material removal rate, and average surface roughness effectively within the input parameters studied.

Vikas[4] were presented an idea about the effect of the various input process parameters like Pulse ON time, Pulse OFF time, Discharge Current and Voltage over the Surface Roughness for an EN41 material. Here, 5 different output parameters concerned with surface roughness like Ra, Rq, Rsk, Rku and Rsm are taken and optimized accordingly, using the Grey-Taguchi method. The Grey-Taguchi method used in the article considers an L27 orthogonal array, which uses a different combination of the 4-input parameters to obtain an optimized value of the surface roughness for EN41 material. The 5 different output values of the surface roughness are calibrated into a single value (i.e. Grade) by calculating their normalized, Δ and ξ values .On the basis of their Grade, the S/N ratio is obtained and accordingly the ANOVA table is generated. It was found that the Current had larger impact over the Surface Roughness value, followed by the Voltage. The experimental results thus, obtained were compared with the theoretical results and they were found very close to one another.

M. Durairaj[5] et.al were analyzed Surface roughness and kerf width are of crucial importance in the field of machining processes. This paper summarizes the Grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in Wire EDM for SS304. The objective of optimization is to attain the minimum kerf width and the best surface quality simultaneously and separately. In this present study stainless steel 304 is used as a work piece, brass wire of 0.25mm diameter used as a tool anddistilled wtater is used as a dielectric fluid .For experimentation Taguchi's L;16, orthogonal array has been used.

The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. For each experiment surface roughness and kerf width was determined by using contact type surf coder and video measuring system respectively. By using multi objective optimization technique grey relational theory, the optimal value is obtained for surface roughness and kerf width and by using Taguchi optimization technique, optimized value is obtained separately. Additionally, the analysis of variance (ANOVA) is toouseful to identify the most important factor.

3. EFFECT OF INPUT PARAMETERS

Based on the discharge phenomena discussed above, the effect of various input parameters on material removal rate (MRR) and surface roughness (Ra) is discussed below.

3.1 Discharge Current

The discharge current (Id) is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (Ra) value. Similar effect on MRR and Ra is produced when the gap voltage (Vg) is increased.

3.2 Pulse-on time

Machining takes place only during the pulse-on time (Ton). When the tool electrode is at negative potential, material removal from the anode (work piece) takes place by bombardment of high energy electrons ejected from the tool surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR.

3.3 Pulse-off time

A non-zero pulse off time is a necessary requirement for EDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time. The surface roughness is found to depend strongly on the spark frequency. When high frequency sparks are used lower values of Ra are observed. It is so because the energy available in a given amount of time is shared by a larger number of sparks leading to shallower discharge craters.

3.4 Flushing Pressure

Apart from the electrical parameters, pressure of the dielectric media may have an effect on the process performance during die sinking EDM. Velocity of the dielectric media jet is directly proportional to the inlet flushing pressure. A high velocity flushing jet would lead to better flushing of debris from the discharge gap thus improving the MRR and Ra values. Forced flow of media also helps in reducing the time required for recovery of dielectric strength of the medium since fresh and previously non-ionized medium is continuously supplied to the gap. This leads to higher process stability. Also, it is found that the dielectric strength of air is dependent on the pressure and increases with an increase in the pressure. This favors an increase in the MRR of the process.

3.5 Tool rotation

Tool electrode rotation is commonly used in small-hole EDM drilling operations. Tool rotation improves flushing and leads to a more uniform electrode wear. The effects of improved flushing are an increased MRR and lower Ra value. At the same time, process stability increases because tool rotation makes it easier to introduce fresh dielectric into discharge gap as the used up dielectric is thrown out due to the centrifugal force. Thus, even with low pulse off times and poor flushing conditions good machining performance is obtained.

4. GENERAL EXPERIMENTAL SETUP

4.1. EXPERIMENTAL SETUP

Electrodes were machined to a rectangular shape and 25mm length. Square piece 25X25 and thickness 6 mm of Titanium material has to be planned.

Figure 4.1: General Experimental Setup

4.2. ELECTRODE MATERIALS

Graphite Electrode

Graphite is the most commonly used material for electrode. Graphite was introduced in EDM industry around 50 years ago. General Electric was the first, well known manufacturer to introduce graphite in EDM industry. It was known by its trade name “Gentrode”. Unlike other metal based electrode material, graphite has certain unique properties which keep it above others as a suitable material for EDM electrode. Its heat resistivity is thousands of degrees higher than other materials. It does not melt like other materials; instead it turns straight into gas from solid state. This is also a disadvantage because, instead of creating chips and staying under the di-electric, it causes a dusty cloud to form in work place.

This is hazardous if not followed precaution. Vacuuming the dust is a good idea to prevent from breathing graphite in while at work place. Graphite, despite being the best option as an electrode material, has some limitations in molecular level. It is porous so when immerged in di-electric fluid it can cause problematic impurities. Trapped moisture can create steam when cutting which damages the electrode. Due to this problem, it is better to use denser graphite which shows little penetration even after long hours of soaking. One other way of using graphite without facing problem is to heat the electrode in oven for an hour at 121°C.

Table 4.1. Properties of Graphite electrode

PROPERTY	UNIT	MATERIAL
Density	g/cc	1.86
Electrical resistivity	(µ.ohm. cm)	850
Average particle size	Micron(µm)	20
Hardness	HB	95
Fluxural strength	Mpa	76

4.3. WORK MATERIAL

4.3.1 WORK MATERIAL DETAILS

Work material –Titanium steel

Work material size–25 x 25 x6 mm thickness

4.3.2 CHEMICAL PROPERTIES

Table 4.2 Chemical properties

13	ELEMENT	COMPOSITION IN WEIGHT %I MAX
1	Titanium	99.2
2	Carbon, C	0.08
3	ferrous Fe	0.25
4	N	0.03
5	O	0.20
6	H	0.015

6.4 .MACHINING PARAMETERS(GENERAL)

Table 4.3 Chemical properties Sparking

Voltage (V)	V80±5%
Discharge Current (A)	10,12,14
Servo Control	Electro Mechanical
Polarity	Normal (Electrode – Positive
Dielectric fluid	I POL EDM fluid;
Flushing side	Flushing with Pressure
Work piece Material	e Steel (Hardened and Tempered)
Electrode Material	Graphite

DESIGN OF EXPERIMENT

Table 4.4Process parameters and their levels

s.no	T ON	TOFF	AMPS
1	7	8	10
2	8	9	12
3	9	10	14

4.6.1 ORTHOGONAL ARRAY L9 FORMATION

Table:4.5 Orthogonal array L9 formation

NO	DESI	T ON	TOFF	AMPS
1	A1B1C1	7	8	10
2	A1B2C2	7	9	12
3	A1B3C3	7	10	14
4	A2B1C2	8	8	12
5	A2B2C3	8	9	14
6	A2B3C1	8	10	10
7	A3B1C3	9	8	14
8	A3B2C1	9	9	10
9	A3B3C2	9	10	12

4.7 EXPERIMENTAL DATA

Table:4.6 Experimental data

DESI	T ON	T OFF	AMPS	RA	MT	MRR
A1B1C1	7	8	10	2.809	28	0.020
A1B2C2	7	9	12	3.578	23	0.029
A1B3C3	7	10	14	5.242	18	0.035
A2B1C2	8	8	12	2.805	19	0.034
A2B2C3	8	9	14	3.684	15	0.048
A2B3C1	8	10	10	3.562	20	0.028
A3B1C3	9	8	14	2.200	13	0.050
A3B2C1	9	9	10	4.278	16	0.040
A3B3C2	9	10	12	5.605	18	0.032

4.8 SURFACE ROUGHNESSES

Table:4.7 R.A And S/N Ratios Values

NO	DESI	T ON	T OFF	AMPS	RA	S/N Response value (db)
1	A1B1C1	7	8	10	2.809	-8.9710
2	A1B2C2	7	9	12	3.578	-11.0728
3	A1B3C3	7	10	14	5.242	-14.3899
4	A2B1C2	8	8	12	2.805	-8.9587
5	A2B2C3	8	9	14	3.684	-11.3264
6	A2B3C1	8	10	10	3.562	-11.0339
7	A3B1C3	9	8	14	2.200	-6.8485
8	A3B2C1	9	9	10	4.278	-12.6248
9	A3B3C2	9	10	12	5.605	-14.9715

4.8.1 ROUGHNESS RESPONSE FOR EACH LEVEL OF THE PROCESS PARAMETER

Table:4.8 Response Table for Signal to Noise Ratios-Smaller is better

Level	A	B	C
Pulse on	-11.478	-8.259	-10.877
Pulse off	-10.440	-11.675	-11.668
Current	-11.482	-13.465	-10.855
Delta	1.042	5.206	0.813
Rank	2	1	3

Table:4.9 Response Table for Means

Level	A	B	C
Pulse on	3.876	2.605	3.550
Pulse off	3.350	3.847	3.996
Current	4.028	4.803	3.709
Delta	0.677	2.198	0.446
Rank	2	1	3

Table:4.10Analysis of Variance

Source	DF	SS	MS	F	P	% of contribution
T ON	2	0.7584	0.3792	0.41	0.708	7
TOFF	2	7.2898	3.6449	3.96	0.202	71
AMPS	2	0.3071	0.1535	0.17	0.857	4
Error	2	1.8409	0.9205			18
Total	8	10.1961				100

Model Summary

S R-sq R-sq(adj) R-sq(pred) 0.959407 81.94% 27.78% 0.00%

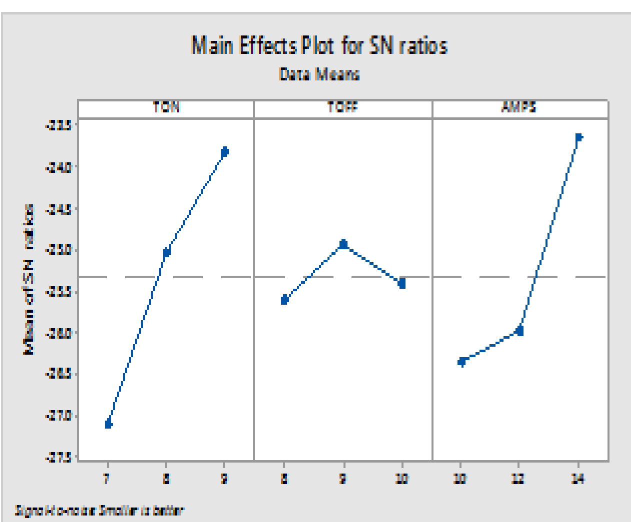

Figure:4.1 main effects plot for SN ratios

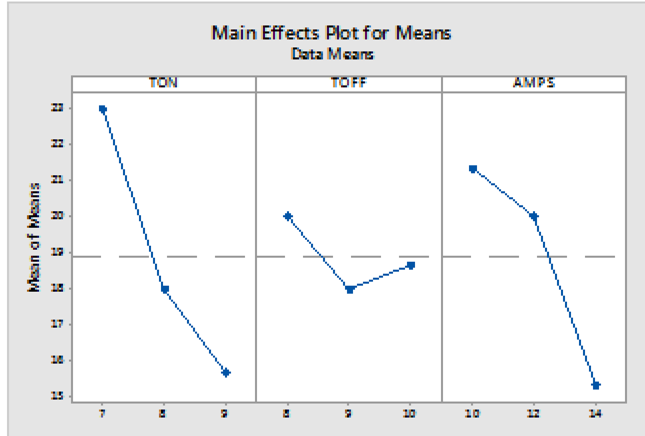

Figure:4.2 main effects plot for means

4.9 MACHINING TIME (ANALYSIS OF RESULT)

Table: 4.11 Machining Time And S/N Ratios Values For The Experiments

NO	DESI	T ON	T OFF	AMPS	RA	S/N Response value (db)
1	A1B1C1	7	8	10	28	-28.9432
2	A1B2C2	7	9	12	23	-27.2346
3	A1B3C3	7	10	14	18	-25.1055
4	A2B1C2	8	8	12	19	-25.5751
5	A2B2C3	8	9	14	15	-23.5218
6	A2B3C1	8	10	10	20	-26.0206
7	A3B1C3	9	8	14	13	-22.2789
8	A3B2C1	9	9	10	16	-24.0824
9	A3B3C2	9	10	12	18	-25.1055

4.9.1 MACHINING TIME FOR EACH LEVEL OF THE PROCESS PARAMETER

Table 4.12 Response Table for Signal to Noise Ratios-Smaller is better

Level	Gap current	Pulse on time	Pulse off time
1	-27.09	-25.60	-26.35
2	-25.04	-24.95	-25.97
3	-23.82	-25.41	-23.64
Delta	3.27	0.65	2.71
Rank	1	3	2

Table 4.13 Response Table for Means

Level	Gap current	Pulse on time	Pulse off time
1	23.00	20.00	21.33
2	18.00	18.00	20.00
3	15.67	18.67	15.33
Delta	7.33	2.00	6.00
Rank	1	3	2

4.9.2 ANALYSIS OF VARIANCE (ANOVA)

Table:4.14 Analysis of Variance (ANOVA) results for the MACHINING TIME

Source	DF	SS	MS	F	P	% of contribution
T ON	2	84.222	84.222	42.11	7.73	0.114
TOFF	2	6.222	6.222	3.111	0.57	0.636
AMPS	2	59.556	59.556	29.778	5.47	0.155
Error	2	10.889	10.889	5.444		
Total	8	160.889				

S R-sq R-sq(adj) R-sq(pred) 2.33333 93.23% 72.93% 0.00%

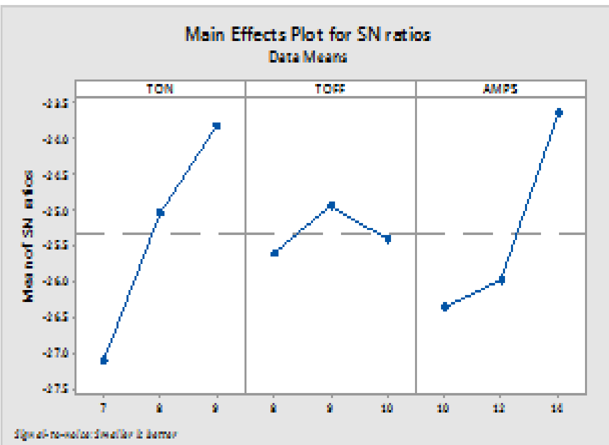

Figure:4.3 Main Effects Plot for SN ratios

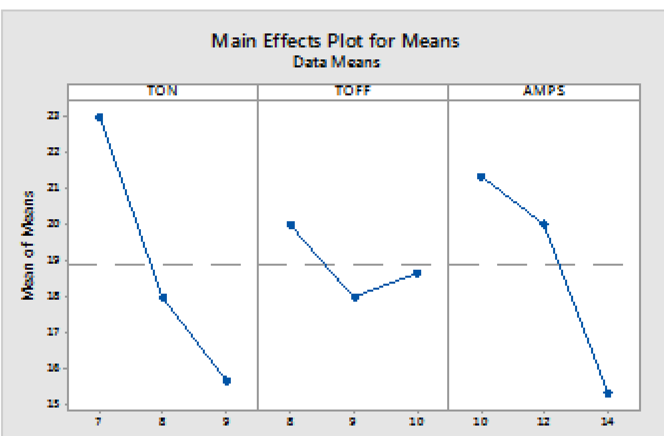

Figure 4.4 :Main Effects Plot for Means

4.10 MRR (ANALYSIS OF RESULT)

Table 4.15 MRR AND S/N RATIOS VALUES FOR THE EXPERIMENTS

NO	DESI	T ON	T OFF	AMPS	RA	S/N Response value (db)
1	A1B1C1	7	8	10	0.020	-33.9794
2	A1B2C2	7	9	12	0.029	-30.7520
3	A1B3C3	7	10	14	0.035	-29.1186
4	A2B1C2	8	8	12	0.034	-29.3704
5	A2B2C3	8	9	14	0.048	-26.3752
6	A2B3C1	8	10	10	0.028	-31.0568
7	A3B1C3	9	8	14	0.050	-26.0206
8	A3B2C1	9	9	10	0.040	-27.9588
9	A3B3C2	9	10	12	0.032	-29.8970

M.R.R- Before Machining Weight-After Machining Weight-Density x Time taken

4.10.1 MRR FOR EACH LEVEL OF THE PROCESS PARAMETER

Table 4.15 Response Table for Signal to Noise Ratios-Larger is better

Level	Pulse on time	Pulse off time	GAP CURRENT
1	-31.28	-29.79	-31.00
2	-28.93	-28.36	-30.01
3	-27.96	-30.02	-27.17
Delta	3.32	1.66	3.83
Rank	2	3	1

Table 4.16 Response Table for Means

Level	Pulse on time	Pulse off time	GAP CURRENT
1	0.02800	0.03467	0.02933
2	0.03667	0.03900	0.03167
3	0.04067	0.03167	0.04433
Delta	0.01267	0.00733	0.01500
Rank	2	3	1

Table 4.17 Analysis of Variance

Source	DF	SS	MS	F	P	% of contribution
T ON	2	0.000252	0.000126	16.90	0.056	34
TOFF	2	0.000082	0.000041	5.48	0.154	11
AMPS	2	0.000391	0.000195	26.25	0.037	53
Error	2	0.000015	0.000007			2
Total	8	0.000739				100

Model Summary

S R-sq R-sq(adj) R-sq(pred) 0.0027285 97.98% 91.94% 59.20%

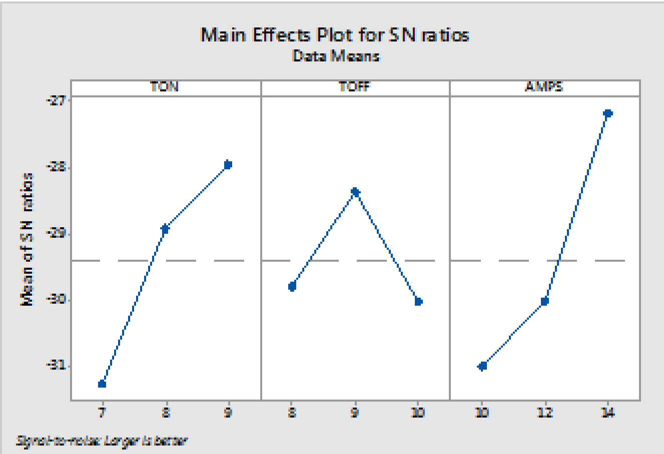

Figure:4.5Main Effect Plot for SN ratios

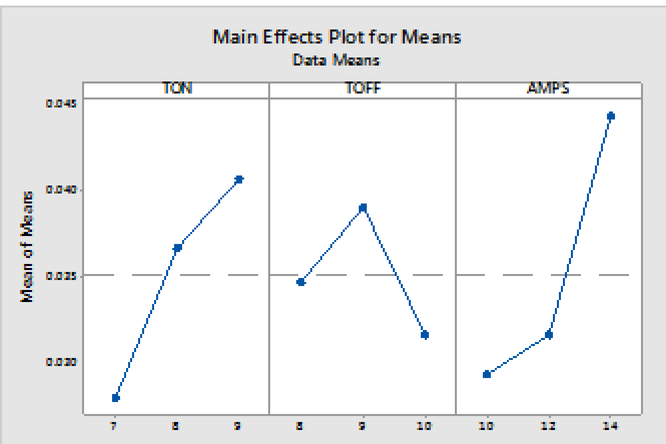

Figure:4.6 Main Effect Plot for Means

5. CONCLUSION AND RESULT

In this experimental study, the Taguchi technique and ANOVA were used to obtain optimal EDM parameters in the machining of Titanium grade II with graphite electrode . The experimental results were evaluated using Taguchi technique. The following conclusion can be drawn.

5.1 OPTIMAL CONTROL FACTOR

1.Surface Roughness-A2(T-ON – 8 µs)B3(T-OFF – 7 µs)C1(Amps-14)

2.Machining Timing- A1(T-ON – 7 µs)B3(T-OFF – 10 µs)C2(Amps-12)

3.Material Removal Rate- A1(T-ON – 8 µs)B3(T-OFF – 10 µs)C2(Amps-10)

5.1.1 Percentage of contribution of Process parameter

1.Surface Roughness-Pulse off time- 71%

2. Machining Timing- Pulse on time52%

3. Material Removal Rate-Amps53%

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