Study of PMEDM Efficiency on EN-31 Steel using Tungsten Powder in Dielectric Fluid

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Abstract – In this present work, study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). Addition of optimum amount of powder in dielectric fluid of EDM impact the Material Removal Rate and inferior the Tool Wear Rate of work piece. Current, Pulse on, Pulse off, and powder concentration were chosen variable to study the process performance. Taguchi Orthogonal Array L9 has been used as a DOE (Design of Experiment) method to program and analyses the experiments. 5 gm/l and 10 gm/l of Tungsten powder (200 mesh size) has been used in EDM oil. It has been investigated the current, pulse on time, powder concentration are the most significant factor that influence the output responses like MRR and TWR. Increase in powder concentration improves process parameters but higher amount of concentration results in arcing which gives inexpedient machining results. EN-31 steel has been selected as workpiece material and Copper is used as electrode.

Index Terms – EDM parameters, EN-31 steel workpiece, Copper electrode and EDM oil as dielectric fluid.

1. INTRODUCTION

Electric discharge machining (EDM) is a non-traditional concept of machining which has been widely used to produce dies and molds. It is works on the principle of conversion of electrical energy into thermal energy through a series of discrete electrical discharges between the electrode and workpiece immersed in a dielectric fluid. Due to the discharge of the capacitor in the circuit, a spark is initiated thereby creating a plasma channel at the point of smallest inter-electrode gap resulting in breakdown of dielectric. There is no physical contact between the electrode and workpiece but instead discharges its current through an insulating dielectric fluid across a very small spark gap (0.025-0.05 mm), this discharge leads to the generation of extremely high temperature between 8000-12000 degree Celsius, causing fusion or partial vaporization of the material at the point of discharge[3]. Due to conversion electrical energy into thermal energy, high intention vaporization cause the erosion of material removal which infect gives poor surface integrity. To overcome poor surface integrity input parameters like current, pulse on, pulse off time palace fateful role. High current and pulse on time induces more material removal rate (MRR) but results in poor surface finish where as high pulse of time generates more time interval to flush away refuse from the spark gap and re-ionization of the dielectric take place, which helps in better surface finish. Suspended powders influence the machining efficiency, these conductive powders enhance the gap distance and improve the surface finish by reducing the spark energy and dispersing the discharge more randomly throughout the thickness of the recast layer is smaller and micro cracks on surface are improved.

2. LITERATURE REVIEW

Jeswani *et al*. [1] they reported that the powder concentration plays important influence on discharge process. The powder concentration increases the gap distance and the discharge rate. While lower concentration of powder the gap increasing is not enough to promote the discharge stability. **V V Potdar** *et al*. [2]. They study that increase in MRR due to increase in powder concentration is mainly that the conductive particle when added into the dielectric fluid, it lowers the breakdown strength of the dielectric fluid. The powder tries to form the plasma bridge between the discharge gap. This facilitates the dispersion of discharge energy into several uniform area and enhance the MRR. **Naveen Kumar** *et al*. [3] they conclude that MRR increased with addition of powder and increase in its concentration. This increase in powder concentration helps to concentrated the discharge energy with more uniformly and increase spark frequency. Whereas TWR reduced, it is because the presence of powder particles absorbed the fraction of heat generated that forms compounds which deposit on the machined surface. This reduces the fraction of heat transferred to the electrode. **S Kumar** *et al*. [4] with tungsten copper electrode, micro hardness of AISI H13 increase by 76 % by migration of tungsten from electrode bodies to the machined surface. Best value of micro hardness was obtained at 6A peak current. Tungsten has a very good potential as an alloying element for deposition during the EDM process. Tungsten and copper were found on surface of work piece material when machined with tungsten copper electrode. **Tzeng Y F** *et al.* [5] alloying elements may be added to the tool or suspended in the dielectric in the form of fine metal powders and they may get deposited on the machine surface either in free form or as carbides by combining with carbon from the breakdown of dielectric medium. **Kansal H K** *et al.* [6] addition of powders in dielectric medium influences the machining efficiency and sparking pattern. These powders enlarge the gap distance and improve surface finish by reducing the spark energy and dispersing the discharge more randomly throughout the surface. The thickness of recast layer is smaller and micro cracks on surface are reduced. Corrosion resistance of material surface is also improved. **Dewes R** *et al.* [7] peak current is the most important electrical parameter affecting the phenomenon of material transfer. Low value of pulse on time provoked a certain amount of electrode wear in EDM. **Wong** *et al.* [8] that the best surface finish obtained by silicon and graphite its states powders is with a low concentration of powder (2g/l). **Mohri** *et al.* [9, 10] and **Narumiya** *et al.* [11]. They used silicon, graphite and aluminum as powder particles of concentration between 2-40 g/l, and their results shows that the gap distance between electrode and workpiece increases with addition of powder concentration and is larger for Al powder. Whereas the best results for MRR is achieved at higher powder concentrations levels for graphite and silicon powders. **Ming and He** [12] and **Yan and Chen** [13]. According to them, the powder materials contribute in the reduction of surface cracks and it gives the smoothness and homogenization of the white layer. The proportional balance between the discharge rate and discharge energy is observed for a powder concentration in the range of 2-5 g/l and also lowest surface roughness levels is obtained as well. **Klocke** *et al*. [14] they study the effect of silicon powder of average particles size range of 10 micron and 10 g/l with flushing flow in the thermal influenced zone. The author uses the high speed framing camera to capture the process and they found the powder suspended in the dielectric change the thermal material removal mechanism. Silicon particles store heat energy during the discharge. After the discharge process the transfer of this energy to the workpiece is balanced with the rapid cool down of the molten surface. Therefore silicon powder suspended in the dielectric promotes a softer transition from the white layer into the matrix material than the observed with powder free dielectric.

3. EXPERIMENTAL SETUP

EN-31 is selected as a workpiece. The chemical composition of workpiece has been shown in the Table 1. Copper electrode of 20 mm diameter has been used as tool electrode. EDM oil is used as dielectric fluid. To ensure that the suspended powder particles do not clog the filtering system mild steel tank of 7 liters volume capacity has been used for conducting experiment as shown in the figure 1. A motor of 1200 rpm is used in the tank for better mixing of the powder in the dielectric. Silicon powder of 200 mesh size is used as powder in dielectric fluid. MRR is calculated by measuring the loss of weight of the workpiece before and after the machining,

MRR= $\frac{(W_i - W_f)}{\rho \times t} x\ 1000\ mm^3/min$ equation (i)

Where,

W_i= Initial weight of work piece material (gms)

W_f= Final weight of work piece material (gms)

t= Time period of trails in minutes

ρ= Density of work piece in gms/cc

TWR is calculate by measuring the loss in tool length,

TWR= $\frac{A\ x\ L}{t}\ mm^3/min$ equation (ii)

Where,

A= front area of electrode (mm3)

L= Loss in length of electrode (mm)

t= time period of trail (minutes)

Table 1.Chemical composition of EN-31.

Workpiece	C	Si	Mn	Cr	S
EN-31	1.1	0.25	0.6	1.40	0.5

Table 2. Chemical composition of Copper.

Workpiece	Cu	Ni	Z	Ti	Pb
Copper	99.78	0.045	0.09	0.029	0.044

Figure 1. Workpiece before machining.

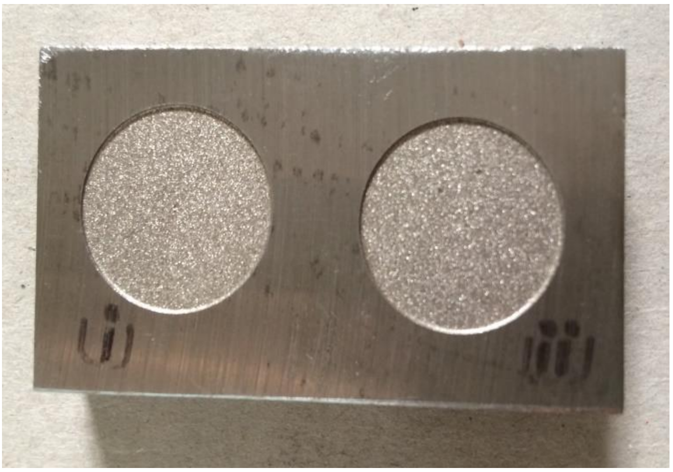


Figure 2. Workpiece after machining.

Figure 3. Copper electrode of 20 mm diameter.

Figure 4. Mid steel tank with 1200 rpm motor

4. EXPERIMENTAL SETTING

The experiments were conducted on EDM Machine (model D-7120), Die sinking EDM type available at Sharda University machine deign lab. A stirring motor is also used to mix the powder with Dielectric fluid properly in the tank. The input parameters like Current, Pulse on, Pulse off and powder concentration are varied during the experiment. And these parameters are selected to study their significance influence to MRR and TWR. The electrode polarity is positive and machining time period of each trial is 10 minutes. The diameter of electrode 20 mm and volume of dielectric fluid is 7 liters.

The input parameters, which will be kept constant during the experimentation, are given in table 3.

Table 3. Constant Parameters

S.No	Parameter	Value set as
1	Open circuit voltage	135±5%
2	Polarity	Positive
3	Machining time	10 minutes
4	Dielectric fluid volume	7 liters

5. METHODOLOGY

The effect of various input parameters i.e. Current, Pulse on time, Pulse off time, Electrode and powder concentration to output responses MRR and TWR were investigated.

The statistical software MINITAB are using for DOE (Design of Experiment). Under DOE we are using Taguchi design to create various level and factors. Orthogonal Array L9 will be used to accommodate combination of 3 level factors that is used to conduct of experiments to measure two values MRR and TWR. We have taken two trials for each experiment. After the conduct of the nine trials, the mean values for MRR and TWR are recorded. For the analysis of the results, Analysis of Variance (ANOVA) was performed.

By applying Analysis of Variance (ANOVA) using Minitab software, significant parameters (MRR) and (TWR) are determined.

Table 4. L9 Orthogonal Array after assigning factors

S.No	Current (I) (Amp)	Pulse On (Ton) (μs)	Pulse Off (Toff) (μs)	Powder Concentration (g/l)
1	3	20	38	0

2	3	50	57	5
3	3	100	85	10
4	5	20	38	10
5	5	50	57	0
6	5	100	85	5
7	9	20	38	5
8	9	50	57	10
9	9	100	85	0

6. RESULTS AND DISCUSSION

MRR result is analyzed by using (ANOVA) Analysis of Variance. The results shows that current, Pulse on time and powder concentration contributed significantly to change in MRR. Current has the highest rank significantly highest contribution to MRR followed by powder concentration and Pulse on time.

Table 5. Measured Value of Mean and S/N Ratio for MRR

S. No	Current (I) (Amp)	Pulse On (Ton) (µs)	Pulse Off (Toff) (µs)	Powder Concentration (gm/l)	Mean MRR(mm^3/ min)	S/N Ratio
1	3	20	38	0	3.4	10.6296
2	3	50	57	5	6.1	15.7066
3	3	100	85	10	8.0	18.0618
4	5	20	57	10	12.9	22.2118
5	5	50	85	0	8.9	18.9878
6	5	100	38	5	14.9	23.4637
7	9	20	85	5	9.3	19.3697
8	9	50	38	10	18.0	25.1055
9	9	100	57	0	13.1	22.3454

Table 6. Response table for mean MRR

Level	Current (Amp)	Pulse On (µs)	Pulse Off (µs)	Powder Concentration (gm/l)
1	5.833	8.533	12.100	8.467
2	12.233	11.000	10.700	10.100
3	13.467	12.000	8.733	12.967
Delta	3.467	3.467	3.367	4.500
Rank	1	3	4	2

Each factor of the main effect plots of MRR are shown in Figure 5. From the figure it can be seen that increase in current and Pulse on time significantly increase the value of MRR. It is also observed that addition of powder particles (10 gm/l) and its concentration in dielectric fluid increase the rate of MRR by 18%.

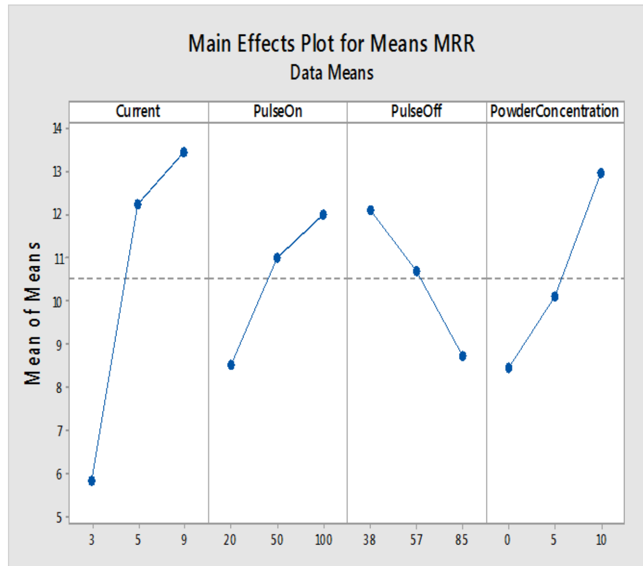


Figure 5. The main effect plots of MRR

When Pulse of time increase MRR decreases, this is due to reason that during Pulse on time there is no spark discharge takes places and it's the time flushing a curse to carry away the debris from the workpiece surface [10]. Hence, whenever Pulse of time increases MRR decreases.

Table 7. Response table for Signal to Noise Ratio (MRR)

Level	Current (Amp)	Pulse On (µs)	Pulse Off (µs)	Concentration (gm/l)
1	14.80	17.40	19.73	17.32
2	21.55	19.93	20.09	19.51
3	22.27	21.29	18.81	21.79
Delta	7.47	3.89	1.28	4.47
Rank	1	3	4	2

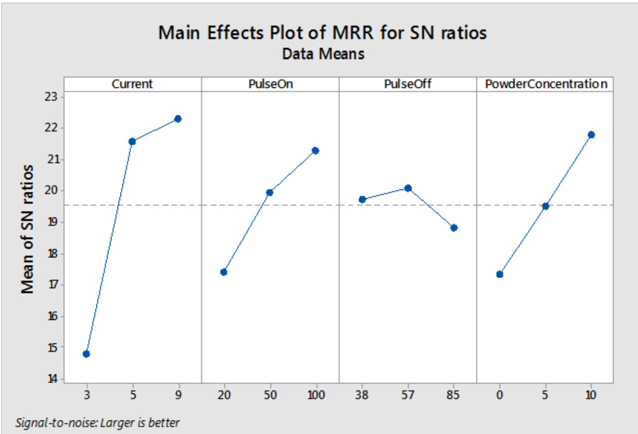


Figure 6. The main effect Plot of S/N Ratio for MRR

Table 8. Analysis of Variance for Mean, using for F-test (MRR)

Table 9. Analysis of Variance for S/N ratio, using for F-test (MRR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	102.012	51.0061	*	0.6456	1
Pulse on	2	23.346	11.6732	*	0.1477	3
Pulse off	2	2.627	1.3134	*	0.0166	4
Concentration	2	30.003	15.0015	*	0.1899	2
Residual Error	0	*	*	*	0	
Total	8	157.988	78.994		100	

The response parameter of mean and S/N ratio of MRR is shown in table 6-7. The F-value and contribution % (P) of each factor obtained from ANOVA method are shown in table 8-9. The significance factor that contributed most is arranged in their ranking manners based on P value. Current place the highest rank and powder concentration Pulse on and Pulse of respectively.

Table 10. Measured value of Mean and S/N ratio for TWR

S.No	Current (I) (Amp)	Pulse On (Ton) (µs)	Pulse Off (T off) (µs)	Powder Concentration (gm/l)	Mean TWR(mm^3/min)	S/N Ratio
1	3	20	38	0	0.2415	12.3417
2	3	50	57	5	0.2156	13.3270
3	3	100	85	10	0.4215	7.5040
4	5	20	57	10	0.2893	10.7730
5	5	50	85	0	0.6610	3.5960
6	5	100	38	5	0.9260	0.6678
7	9	20	85	5	0.7001	3.0968
8	9	50	38	10	0.7395	2.6212
9	9	100	57	0	1.2705	-2.07949

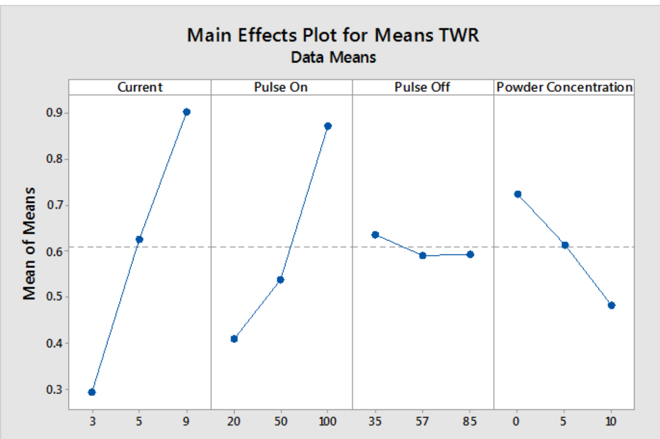
The results of TWR are analyzed by using ANOVA-Analysis of Variance. The results shows that current, Pulse on time, Pulse of time and concentration contributed significantly to change in TWR. Current has the highest rank, significantly highest contribution to MRR. Whereas Pulse of time has the lowest rank that significantly contributed TWR. Response table for mean and S/N ratio TWR are shown in table 11-12 respectively.

Table 11. Response Table for Mean TWR

Level	Current (Amp)	Pulse On (µs)	Pulse Off(µs)	Powder Concentration (gm/l)
1	0.2929	0.4103	0.6357	0.7243
2	0.6254	0.5387	0.5918	0.6139

3	0.9034	0.8727	0.5942	0.4834
Delta	0.6105	0.4624	0.0439	0.2409
Rank	1	2	4	3

The main effect plots of TWR at each factors are shown in figure 7. As the current and pulse on time increases the TWR also increases. From the figure 7, it can be seen that increase in current and pulse on time significantly increase the value of TWR by 56%. This is due to reason that high current and more pulse on time increase the spark energy leading to higher heat being transferred to electrode and more heat being generated, which eventually leads to more TWR.



,Figure 7. The main effects plot of Means TWR

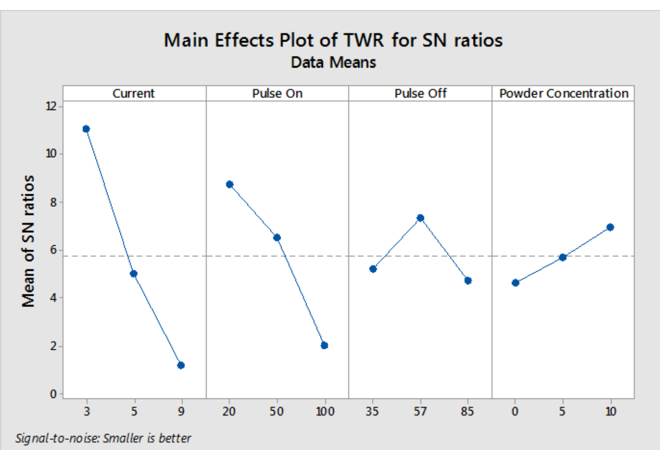


Figure 8. The main effect plot of S/N ratio for TWR

However increase in powder concentration, TWR is reduced. According to Ajay Batish et al [10] when the powder particles are present in the inter-electrode gap, even if the discharges are concentrated and uniform, a fraction of the heat generated is observed by the powder forming compounds that deposits on the machined surface. This phenomena reduces the fraction of heat transferred to the electrode. But, an increased powder concentration of beyond 10 % may lead to undesirable arcing.

Table 12. Response table for Signal to Noise Ratio (TWR)

Level	Current (Amp)	Pulse On (µs)	Pulse Off(µs)	Powder Concentration (gm/l)
1	11.058	8.737	5.210	4.619
2	5.012	6.515	7.340	5.697
3	1.213	2.031	4.732	6.966
Delta	9.845	6.706	2.608	2.347
Rank	1	2	3	4

While it is observed, when pulse off time increase, TWR decrease by 3.6%, this is due to the reason that during pulse off time there is no spark discharge take place.

Table 13. Analysis of Variance for Mean, using F-test (TWR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	0.560558	0.280279	*	0.5643	1
Pulse on	2	0.341803	0.170902	*	0.3441	2
Pulse off	2	0.003650	0.001825	*	0.0036	4
Concentration	2	0.087250	0.043625	*	0.0878	3
Residual	0	0	0	0		

Error						
Total	8	0.993260	0.4966		100	

The response parameters of mean and S/N ratio of TWR are shown in table 11 and 12. The percentage contribution (P) of each factor for mean and S/N ratio obtained from ANOVA methods are shown in table 13 and 14. From the table, it concludes that, based on P value, the significance factor that contributed most are arranged in their ranking manners.

Table 14. Analysis of Variance for S/N Ratio, using F-test (TWR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	147.900	73.9500	*	0.6220	1
Pulse on	2	70.021	35.0103	*	0.2944	2
Pulse off	2	11.566	5.7832	*	0.0486	3
Concentration	2	8.279	4.1395	*	0.0347	4
Residual Error	0	0	0	0	0	
Total	8	237.766	118.883		100	

Current place the highest rank and pulse on, powder concentration and pulse off respectively for Mean TWR whereas for S/N ratio of TWR most significant factor that contributed is current with 62.67%, next significant factor is pulse on with 29.44% and the third significant factor is pulse off with 4.86% and the forth significant factor is powder concentration with 3.47%.

7. CONCLUSION

In this study the influence of PMEDM with Tungsten copper electrode and silicon powder in EDM oil dielectric has been investigated. MRR and TWR were analyzed for effects of different input parameters. The following conclusion has been found out from the experiment and results

1. Higher current and higher pulse on time influence most significantly in both MRR and TWR. It has been seen from the results that when current and pulse on time increases Material Removal Rate of work piece is increase by 59% and 11% respectively.

2. When concentration of Tungsten powder increases from 0-10 g/l, MRR also increase but TWR decrease as the concentration increases. From the result's observation, it concludes that when powder concentration increases from 0 to 10 g/l, TWR decrease by 8%.

3. While increase in pulse off time, MRR reduced by 10.2% and TWR by 3.6%.

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