Optimization of process parameters of CNC Wire Cut EDM for steel EN45

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Abstract:

Wire Electric Discharge Machining (WEDM) process is a commonly used process to cut conductive materials of complex and intricate shapes of components. A suitable modeling is needed to improve product accuracy and machining economics. A number of researchers have attempted in this field previously. Performance characteristics, namely Material Removal Rate (MRR) and Surface Roughness (SR) are to predict by general purpose software, MINITAB for its analysis. EN45 material is selected as work material to conduct this experiment. A0.25mm diameter brass coated copper wire was used as tool electrode to cut the material. According to Taguchi's L9orthogonal array experiments were planned. Under different cutting conditions of pulse on time, pulse off time, servo voltage, peak current, each experiment has been performed. In each experiment the performance characteristics such as material removal rate and surface roughness were carefully measured and calculated.

1. Introduction

EDM machining technique was first discovered by an English scientist in 1770s. However EDM was not fully taken advantage of until 1943 when Russian scientists leaned how the erosive effect of the technique could be controlled and used for machining purpose it is used to cut electric conducted material. EDM has been replacing gridding, milling, drilling and other traditional machining operations and is now a well-established a machining process in many manufacturing industries. It is used to cut complex geometric shapes and hard materials.

1.1 Introduction to Wire-EDM

Wire electric discharged machining has been improved significantly to meet the requirements in various manufacturing filed especially in die-casting industry in last few years. It is thermo electric process in which material is eroded from the work piece by a series of discrete sparks between the work piece and the wire electrode separated by a thin film of the electric flood that is continuously fad to the machining zone to flush away the eroded partials. A small diameter wire ranges from 0.05-0.3mm applied as tool material.

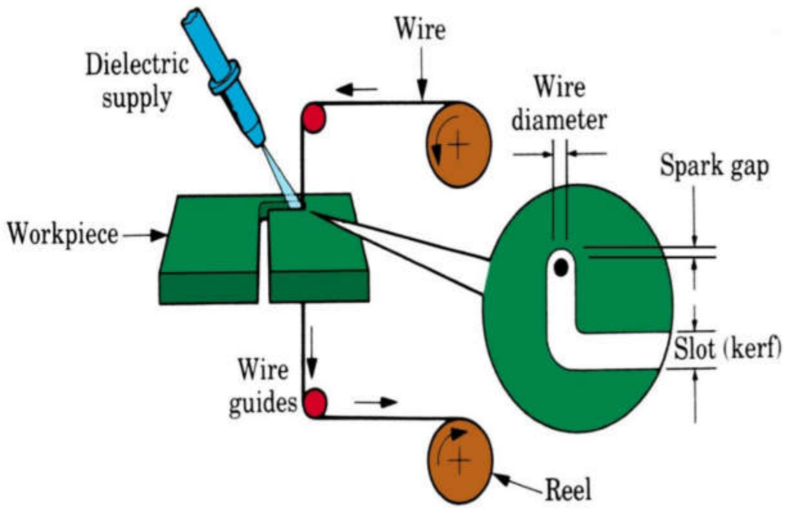

Figure 1.1 Details of WEDM Machining Process

1.2 Process Parameters of WEDM

1.2.1 Pulse on time (T_{ON})

The pulse on time (T_{ON}) represents the duration of time in micro seconds, µs. During this time, Electrical discharge occurs between workpiece and the electrode wire. During this time the voltage (VP), is applied across the electrodes. For getting long discharge, large value of ON time to be selected.

1.2.2 Pulse off time (T_{OFF})

The pulse off time (T_{OFF}) represents the duration of time in Micro Seconds, µs. During this time no voltage is applied consequently no electric discharge between the workpiece and wire electrode takes place. Low value of discharge leads to wire breakage and due to this cutting efficiency also reduces**.**

1.2.3 Peak Current (I_P)

The peak current is represented by IP and it is the maximum amount of current flowing through the circuit during pulse on time. It is measured in amperage. This parameter actually reveals how much power is used in WEDM. Higher value of peak current is required for roughing operations and cutting rate also increases with increase in peak current.

1.2.4 Servo voltage (S_V)

This parameter actually controls the wire movement i.e. (advancing and retracting). So if SV is applied more, than gap between wire electrode and workpiece will be wider and hence electric spark will be less and machining rate will be low. If SV is less, less gap is found, so electric sparks are more then automatically machining/cutting rate will be more.

1.2.5 Wire Tension (W_T)

Wire tension controls how much the wire is to be stretched between upper and lower wire guides. This is a gram-equivalent load with which the continuously wire feed is kept under tension so that it remains straight between the wire guides. More the thickness of job more is the tension required. Improper setting of tension may result in the job inaccuracies as well as wire breakage.

1.2.6 Wire feed (W_F)

Wire feed is the amount at which the wire-electrode travels along the wire guide path and it fed continuously between the wire guides.

1.2.7 Dielectric fluid

Dielectric fluid is indispensable parameter of WEDM. It is used to cool the wire and flush off the debris from the gap. Distilled water is the commonly used dielectric fluid for WEDM.

1.2.8 Flushing Pressure

Flushing Pressure is a selection of flushing input pressure of the dielectric. The flushing pressure range on this machine is either 1 (High) or 0 (low). High input pressure of water dielectric is necessary for cutting with higher values of pulse power and also while cutting the work piece of more thickness. Low input pressure is used for thin work piece and in trim cuts.

1.3 Performance measures of WEDM

1.3.1 Material Removal rate (MRR)

Material removal rate is a very important parameter which influences productivity of any process. As MRR increases, the economic benefits of using WEDM will be worthy for any firm. This factor depends upon number of input parameters which are related with WEDM. Lot of research had been done in past to maximize the MRR by different models and approaches. MRR is generally can be calculated using following equation:

$$\text{MRR}=\frac{K*A}{T_m}$$

1.3.2 Surface Roughness (R_a)

Surface roughness is also the very important parameter whose value is required to be minimized. To obtain good surface roughness, certain factors need to be controlled and these are electrical parameters, dielectric fluid, work piece material. Researchers suggest that with increase of discharge energy, roughness of machined surfaces also increases. As larger discharge energy will produce larger crater & hence larger value of surface roughness on the workpiece would be formed.

1.4 Steps in Taguchi Methodology

1. Decide the important input process parameter and their levels response parameters and their characteristics.
2. Select the appropriate OA and assign the parameters to its various problems.
3. Conducts experiments for the levels given in each row randomly and note down the value of response parameter.
4. Study factor effects and find out the optimum combination of the input parameters. Calculate the best value of the response characteristics.

1.5 Work-piece material

EN with a capital 'N' stands for European Norm which translates to European Standard. It is a steel with a high carbon content, traces of manganese that effect the metal's properties, and that it is generally used for springs (such as the suspension springs on old cars). Untempered EN45 is harder than mild steel, and will not suffer as much from burs or require as much repair and therefore have a longer life. EN45 is commonly used in the automotive industries for the manufacture and repair of leaf springs.

1.5.1 Chemical composition:

Grade	Min.%	Max. %
Carbon, C	0.5	0.6
Maganese, Mn	0.7	1.1
Silicon, Si	1.5	2.0
Sulphur, S	-	0.05
Phosphorous	-	0.05

1.5.2 Physical properties:

Ultimate Tensile Strength(MPa)	621
Modulus of elasticity, E (GPa)	204
Fatigue strength coefficient,o_f (MPa)	948
Fatigue strength exponent, b	-0.092
Fatigue ductility coefficient, e_f	0.26
Fatigue ductility exponent, c	-0.445

2. Design of Experiment

In this work the relationship between control factors and responses like MRR and surface roughness is to be established. The method is used to formulate the experimental layout to analyze the effect of each parameter on machining characteristics and to predict the optimum choice of input.

2.1 L_9 Orthogonal array (4 parameters and 3 levels):

In this, four input machining parameters were used as control factors and each parameter was designed for three levels. The orthogonal array is presented in below table:

Table 2.1: orthogonal array for Taguchi design

S.No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2.2: Levels of process parameters

S.No	Parameters	Levels		
		1	2	3
1	Current (A)	210	220	230
2	Voltage (V)	50	60	70
3	Pulse On Time	115	120	125
4	Pulse Off Time	30	35	40

2.2 Input parameters:

Table 2.3: Input parameters

S.No	Voltage	Current	T_{ON}	T_{OFF}
1	50	210	115	30
2	50	220	120	35
3	50	230	125	40
4	60	210	115	40
5	60	220	120	30
6	60	230	125	35
7	70	210	115	35
8	70	220	120	40
9	70	230	125	30

3. Results and Discussion:

Table 3.1: Results of orthogonal array

S.No.	Voltage (V)	Current (A)	T_{ON} (µs)	T_{OFF} (µs)	Machine Time	MRR (mm^3/s)	S.R (µm)
1	50	210	115	30	684	0.25117	1.87
2	50	220	120	35	631	0.2723	2.33
3	50	230	125	40	646	0.26595	1.75
4	60	210	115	40	865	0.19861	2.51
5	60	220	120	30	591	0.2907	2.48
6	60	230	125	35	906	0.18963	1.35
7	70	210	115	35	820	0.20951	1.94

8	**70**	**220**	**120**	**40**	**1286**	**0.13359**	**1.76**
9	**70**	**230**	**125**	**30**	**781**	**0.21998**	**1.83**

3.1 Analysis and Discussion of experimental Results:

The response table was used to establish statistically significant machining parameters and the influence of these parameters on the surface roughness and the MRR. In Taguchi method , a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is further transformed in to a signal-to-noSise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics; lower the better (LB), nominal is the best (NB), and higher is better (HB). In WEDM, the lower surface roughness and higher MRR are indication of better performance. For the HB and LB, the definitions of the loss function (L) for machining performance results (MRR, surface roughness) of n repeated number are,

$$L_{HB} = 1/n \sum_{i=1}^{n} \frac{1}{Y_{MRR}^2}$$

$$L_{HB} = 1/n \sum_{i=1}^{n} Y_{SF}^2$$

Where Y_{MRR} and Y_{SF} are the response for material removal rate and surface finish respectively and n denotes the number of experiments. The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below:

S/N ratio for MRR = -10 log 10 (L_{HB})

S/N ratio for SF = -10 log 10 (L_{LB})

Regardless of the category of the performance characteristics, greater S/N values correspond to a better performance. Therefore, the optimum level of the machining parameters is the level with the greatest S/N ratio value. By applying these Equations from (2) to (5), the S/N ratio values for each experiment of L16 (Table 4) was calculated (Table Based on the analysis of S/N ratio, the optimal machining performance for MRR from means graph was obtained.

Analysis of result was done by Minitab software. This analysis is done by plotting graph and response table. The graphs are plotted for means and S/N ratio.

The graphs were plotted for MRR and surface roughness. The graphs were plotted for all the input parameters i.e; effect of all four process parameters on MRR and SR can be shown with the help of response table and graph.

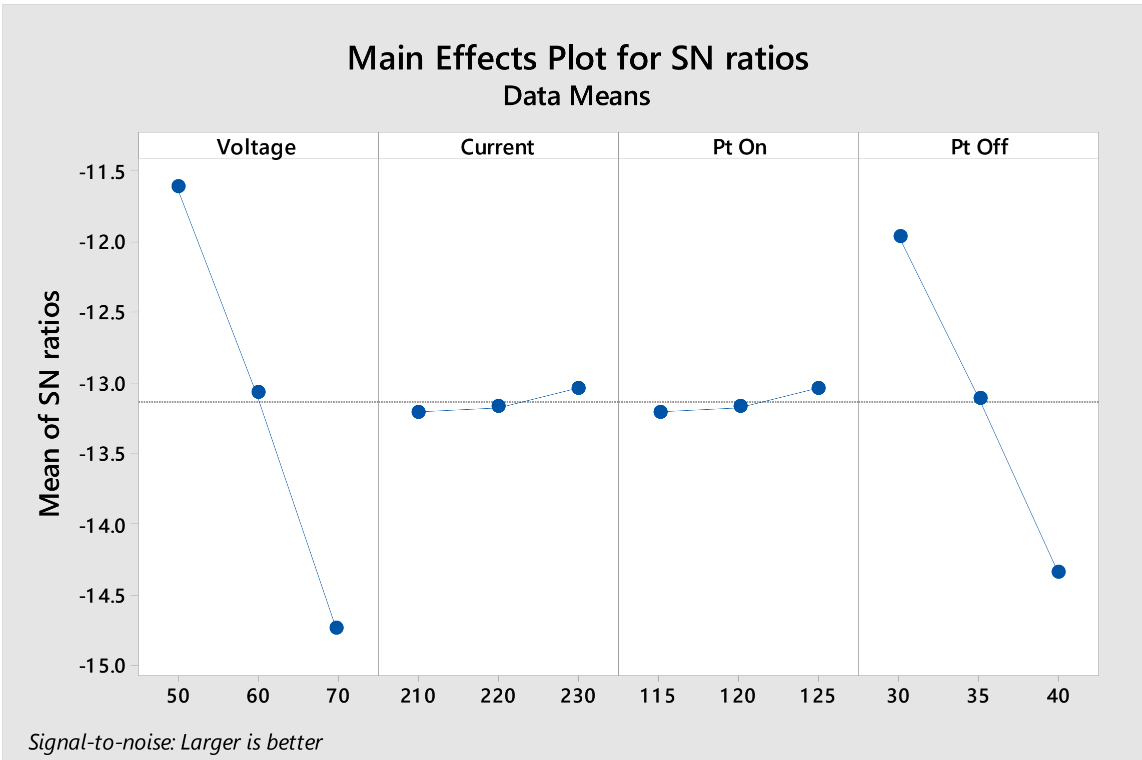

Figure 1.2: SN ratio for MRR

The above fig shows that as voltage increases MRR decreases linearly. As current increases, MRR increases first with slow rate and then at faster rate. As pulse ON time increases, MRR increases first with slow rate and then at faster rate. As pulse OFF time increases, MRR decreases linearly.

Table 3.1: Response Table for Signal to Noise Ratios for MRR

Level	Voltage	Current	Pt On	Pt Off
1	-11.60	-13.21	-13.21	-11.96
2	-13.07	-13.17	-13.17	-13.11
3	-14.74	-13.03	-13.03	-14.34
Delta	3.14	0.17	0.17	2.38
Rank	1	3.5	3.5	2

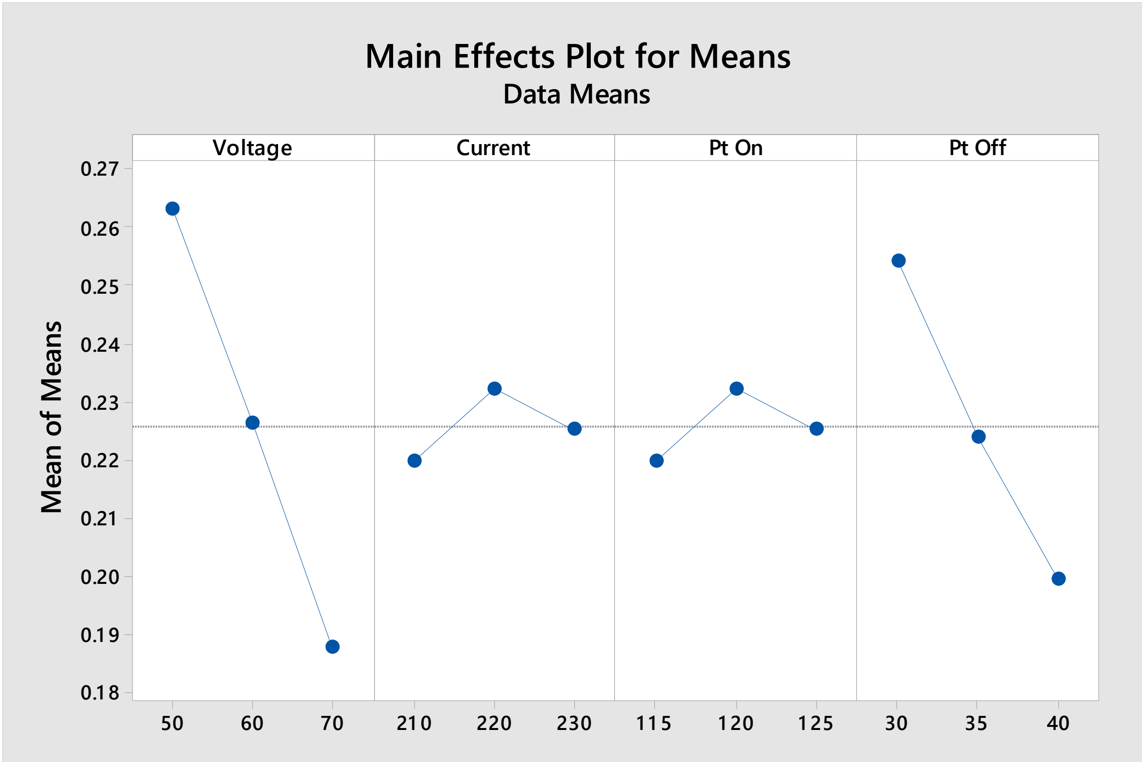

Figure 1.2: Mean of Mean for MRR

From the graph it can be seen that as voltage increases, MRR decreases. As current increases it first increases then decrease. As pulse on time increases it first increase then decrease. As pulse off time increase MRR first decrease with slower rate then decreases rapidly.

From above two graphs it can be concluded that the best optimized solution is A1B3C3D1 which will give the highest material removal rate as in table below.

Table 3.4: Response Table for Means

Level	Voltage	Current	Pt On	Pt Off
1	0.2631	0.2198	0.2198	0.2540
2	0.2263	0.2322	0.2322	0.2238
3	0.1877	0.2252	0.2252	0.1994
Delta	0.0754	0.0124	0.0124	0.0546
Rank	1	3.5	3.5	2

The above graph shows that as voltage increase, the surface roughness first decreases and then increases. As current increases, it first decreases with slower rate then increases rapidly. As pulse on time increases it first decrease then increase with faster rate. As pulse off time increase, surface roughness first increase then decreases.

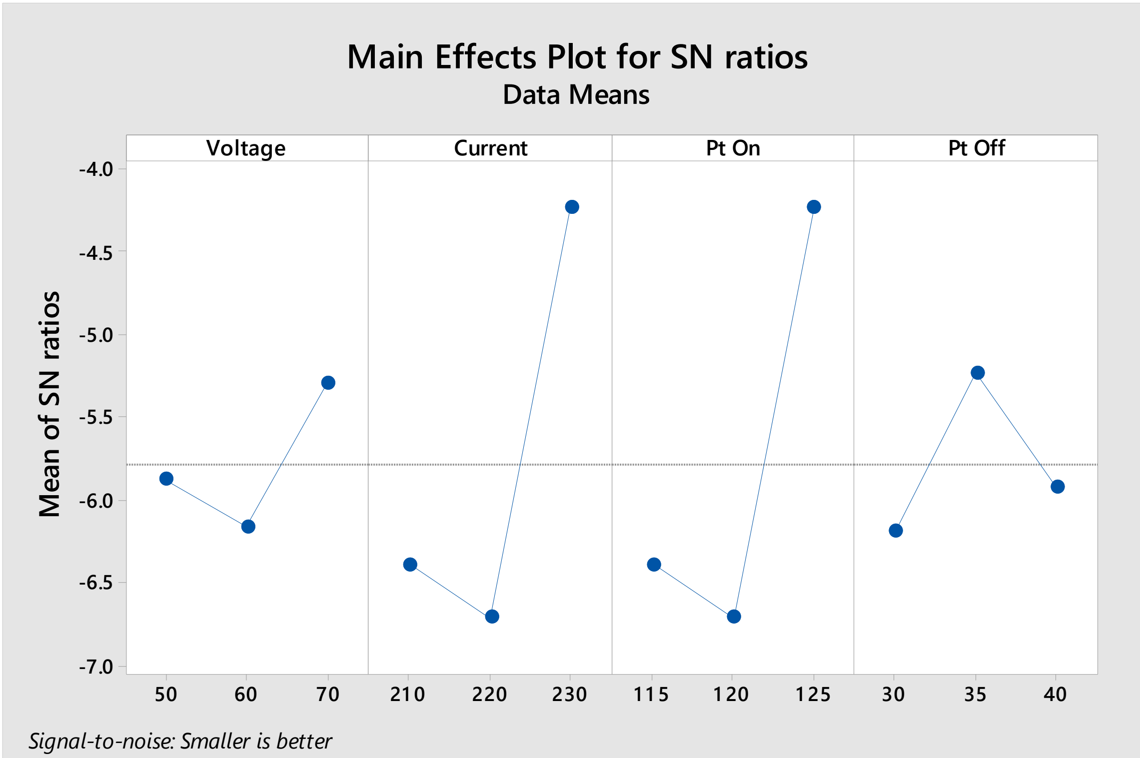

Figure 1.4: SN ratio for SR

The above graph shows that as voltage increase, the surface roughness first decreases and then increases. As current increases, it first decreases with slower rate then increases rapidly. As pulse on time increases it first decrease then increase with faster rate. As pulse off time increase, surface roughness first increase then decreases.

Table 3.5: Response Table for Signal to Noise Ratios

Level	Voltage	Current	Pt On	Pt Off
1	-5.882	-6.395	-6.395	-6.192
2	-6.163	-6.715	-6.715	-5.237
3	-5.305	-4.239	-4.239	-5.921
Delta	0.858	2.477	2.477	0.955
Rank	4	1.5	1.5	3

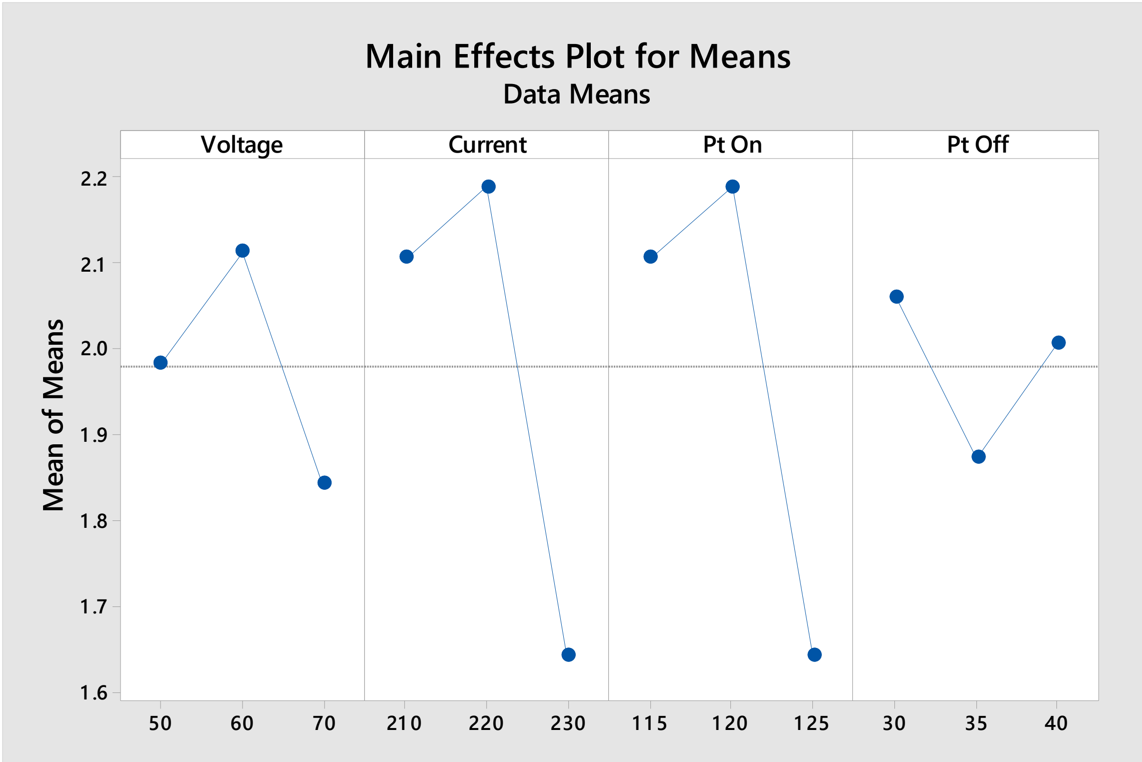

Figure 1.5: Mean of Mean for SR

The above graph shows that as voltage increase, the surface roughness first increases and then decreases. As current increases, it first increases with slower rate then decreases rapidly. As pulse on time increases it first increase slowly then decrease with faster rate. As pulse off time increase, surface roughness first decrease then increases.

The surface roughness is to be minimized as much as possible so we can consider smaller is better for surface roughness. Therefore the optimized solution for surface roughness is A2B2C2D1 as shown in table below.

Table 4.6: Response Table for Means for SR

Level	Voltage	Current	Pt On	Pt Off
1	1.983	2.107	2.107	2.060
2	2.113	2.190	2.190	1.873
3	1.843	1.643	1.643	2.007
Delta	0.270	0.547	0.547	0.187
Rank	3	1.5	1.5	4

CONCLUSIONS:

Steel EN 45 was machined by wire electric discharge machine to study the effect of electrical process parameters on material removal rate and surface roughness. Based on the conducted experiments the following conclusion can be made:

1. As current increases, MRR also increases.
2. With increase in voltage MRR decreases constantly.
3. MRR increases with increase in pulse on time.
4. MRR decreases with increase in pulse off time.
5. Surface roughness first decreases then increase with increase in voltage.
6. Surface roughness first decrease then increase rapidly with increase in current.
7. Surface roughness first decrease then increase rapidly with increase in pulse on time.
8. Surface roughness first increase then decrease with increase in pulse off time.

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