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Research Article

Parameter Optimization of Wire EDM for H-13 Tool Steel

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Abstract

Wire Electrical Discharge Machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. H13 Hot Work Tool Steel has high hot tensile strength, hot wear-resistance and toughness. Good thermal conductivity and insensitiveness to hot cracking, making it suitable not only for hot die applications but also plastic moulds. In this study, it is found that most predominant factors for the maximum material removal rate which is 22.21 mm3/min are current which was found to be 200A and Pulse ON Time 125 μs, however rest four factors (voltage 20V, pulse off time 40μs, wire tension 8N and wire feed 7mm/min) has less impact as compare to the predominant factors. The most predominant factors for Minimum surface roughness which is 0.89μm are wire tension 10N, pulse on time 115μs and servo voltage 60V. However, rest three factors pulse off time 60 μs, peak current 140 A and wire feed 7mm/min has less impact as compare to the predominant factors.

Keywords: *WEDM; Taguchi Method, ANOVA, TON; TOFF; MRR; WT; WF; SV; IP*

1. Introduction

Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. It is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM in figure 1 utilizes a continuously traveling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

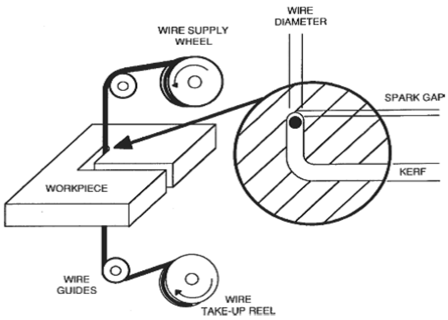

Figure 1: Wire Electric Discharge Machining

The material removal mechanism of WEDM is very similar to the conventional EDM Process involving the erosion effect of produced by the electrical discharge (sparks). In WEDM, material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone. The basic scheme of Wire electric discharge machining is illustrated in figure 2 However, today's WEDM process is commonly conducted on the work piece that are totally submerged in a tank filled with dielectric fluid. Such a submerged method of WEDM promotes temperature stabilization and efficient flushing especially in cases where the work piece has varying thickness. The WEDM process make use of electrical Energy generating a channel of plasma between the cathode and anode, and turns into thermal

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energy at a temperature in the range between of 8000-12000°C or as high as 20,000°C initializing a substantial amount of heating and melting of material on the surface of each pole. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and plush the molten particle from the pole surface in the form of microscopic debris.

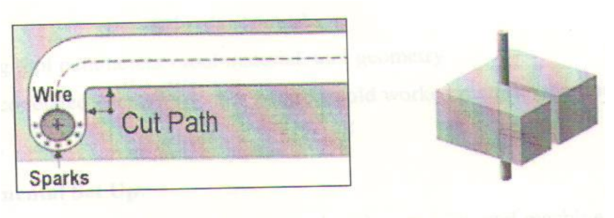

Figure 2: Wire Electric Discharge Machining Process

2. Materials and methods

2.1. Work Material

H13 Hot Work Tool Steel has high hot tensile strength, hot wear-resistance and toughness. Good thermal conductivity and insensitiveness to hot cracking. H13 type grade offers a good resistance to softening, up to 600ºC, combined with good stability in hardening and high toughness, making it suitable not only for hot die applications but also for plastic moulds. It has many applications for making Hot punches and dies for blanking, bending, swaging and forging, hot extrusion dies for aluminum cores, ejector pins, inserts and nozzles for aluminum, tin and lead die casting. The table 1 shows the chemical composition of H-13 Hot Tool Steel.

Table 1: Chemical composition of H-13 Hot Tool Steel

Spectro Analysis Test Report	Sr No.	1
	Material	H13
	Carbon(%)	0.316
	Manganese(%)	0.338
	Phosphorus(%)	0.0125
	Sulphur(%)	0.0134
	Silicon(%)	0.8025
	Chromium(%)	4.956
	Vanadium(%)	1.09
	Molydeum(%)	1.285

2.2. Schematic of machining

The experiments were carried out on a wire-cut EDM machine (fig 3) ELEKTRA SPRINTCUT 734. The WEDM machine tool has the following specifications:

Design: Fixed column, moving table
Table size: 440 x 650 mm
Max. workpiece height: 200 mm
Max. workpiece weight : 500 kg
Main table traverse (X, Y) : 300, 400 mm
Auxiliary table traverse (u, v) : 80, 80 mm
Wire electrode diameter: 0.25 mm (Standard)
Generator: ELPULS-40 A DLX
Controlled axes: X, Y, U, V
Simultaneous / independent
Interpolation: Linear & Circular
Input Power supply : 3 phase, AC 415 V, 50 Hz
Connected load: 10 KVA
Average power consumption: 6 to 7 KVA

Figure 3: Elektra Sprintcut 734

2.3 Experimentation Methods

In this experiment Taguchi's L18 orthogonal array method is being used. The results are being analysed by using ANOVA method and Signal to Noise ratios are used to optimize the objective parameters.

3. Measurement of experimental parameters

3.1 Cutting Rate

For WEDM, cutting rate is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study cutting rate is a measure of job cutting which is digitally displayed on the screen of the machine and is given quantitatively in mm/min.

3.2 Surface Roughness

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. 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. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length. In this work the surface roughness was measured by MarSurf PS1 (Fig.4.7). The MarSurf PS1 is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in μm.

Input process parameters such as Wire Tension (A), Wire Feed (B), Pulse-on time (C), Pulse-off time (D), Servo Voltage (E) and Peak current (F) used in this study are shown in Table 2. Gap Voltage in the range of 20 to 60 Volts; T on in the range of 115 to 125; T off in the range of 40 to 60; Peak current in the range of 140 to 200 amps. To perform the experimental design, two levels of machining parameter of Wire Tension and three levels of each machining parameters (Wire Feed, Ton, Toff, Gap Voltage and Gap Current) were selected as shown in table 2.

Table 2: Process Parameters and their Ranges

Process Parameters	Symbols	Process Designation	Level 1	Level 2	Level 3
Wire Tension	WT	A	8	10	-
Wire Feed	WF	B	7	8	9
Pulse-on Time	T on	C	115	120	125
Pulse-off Time	T off	D	40	50	60
Servo voltage	SV	E	20	40	60
Peak current	IP	F	140	170	200

4. Data analysis and discussion

An L18 orthogonal array is used to specify the experiments. To take in to account the effect of noise factors and to study the nonlinear relationship among the process variables, five values of cutting speeds were taken at each work piece sample of area 5x5 mm^2. The cutting speeds & MRR for the H13 Material is shown in Table 3 & the value of Surface Roughness (Ra) by using MarSurf PS1 is shown in Table 4. S/N data of the MRR & Ra are also given in table 5. The signals to noise ratio (S/N) ratio of the individual runs, which is calculated as:

$$S/N=-10\text{Log } 1/R \{ \sum_{j=1}^{R} (y_i - y_o)\}$$

Where y_i is the individual cutting speed in a run

Table 3: MRR value for the H13 Material

MATERIAL - H13							EXPERIMENT – MRR							
Exp. No.	WT	WF	T on	T off	SV	IP	Cutting Speed						b*h	MRR (mm3/ min)
	A	B	C	D	E	F	1	2	3	4	5	Avg.		
1	8	7	115	40	20	140	2.1	2.2	2.2	2.3	2.2	2.198	4.935	10.847
2	8	7	120	50	40	170	1.4	1.3	1.3	1.3	1.3	1.318	4.935	6.5043
3	8	7	125	60	60	200	0.9	0.9	0.9	0.8	0.8	0.85	4.935	4.1948
4	8	8	115	40	40	170	1.6	1.7	1.6	1.7	1.6	1.654	4.935	8.1625
5	8	8	120	50	60	200	1.1	1	1	1.1	1.2	1.076	4.935	5.3101
6	8	8	125	60	20	140	1.3	1.4	1.3	1.4	1.2	1.324	4.935	6.5339
7	8	9	115	50	20	200	1.3	1.3	1.4	1.3	1.3	1.318	4.935	6.5043
8	8	9	120	60	40	140	0.8	0.7	0.8	0.8	0.8	0.756	4.935	3.7309
9	8	9	125	40	60	170	2.2	2.3	2.2	2.2	2.4	2.246	4.935	11.084
10	10	7	115	60	60	170	0.4	0.4	0.4	0.4	0.4	0.402	4.935	1.9839
11	10	7	120	40	20	200	3.3	3.4	3.2	3.2	3.1	3.23	4.935	15.94
12	10	7	125	50	40	140	1.8	1.8	1.7	1.8	1.8	1.772	4.935	8.7448
13	10	8	115	50	60	140	0.6	0.6	0.7	0.7	0.7	0.65	4.935	3.2078
14	10	8	120	60	20	170	1	1	1	1	1	1.022	4.935	5.0436
15	10	8	125	40	40	200	2.8	3.5	3.4	3.4	3.4	3.296	4.935	16.266
16	10	9	115	60	40	200	0.6	0.6	0.6	0.6	0.6	0.582	4.935	2.8722
17	10	9	120	40	60	140	1.8	1.6	1.7	1.7	1.8	1.722	4.935	8.4981
18	10	9	125	50	20	170	2.2	2.2	2.2	2.2	2	2.19	4.935	10.808

Table 4: Ra value for the H13 Material

Exp. No.	WT	WF	T on	T off	SV	IP	Ra in μm			
	A	B	C	D	E	F	1	2	3	Avg.Ra
1	8	7	115	40	20	140	1.422	1.937	1.624	1.661
2	8	7	120	50	40	170	2.985	2.842	2.926	2.918
3	8	7	125	60	60	200	1.791	1.882	1.918	1.864
4	8	8	115	40	40	170	4.12	4.068	3.986	4.058
5	8	8	120	50	60	200	3.02	2.287	2.118	2.475
6	8	8	125	60	20	140	2.426	2.888	2.929	2.748
7	8	9	115	50	20	200	4.191	4.086	4.242	4.173
8	8	9	120	60	40	140	1.721	1.928	1.884	1.844
9	8	9	125	40	60	170	4.022	3.901	3.886	3.936
10	10	7	115	60	60	170	1.386	1.428	2.02	1.611
11	10	7	120	40	20	200	3.621	3.524	3.432	3.526

12	10	7	125	50	40	140	1.006	2.021	1.886	1.638
13	10	8	115	50	60	140	1.553	1.448	1.582	1.528
14	10	8	120	60	20	170	2.999	3.062	3.122	3.061
15	10	8	125	40	40	200	3.802	3.718	3.666	3.729
16	10	9	115	60	40	200	1.75	1.862	2.12	1.911
17	10	9	120	40	60	140	2.95	2.768	2.786	2.835
18	10	9	125	50	20	170	5.026	4.998	4.912	4.979

Table 5: S/N data of the MRR & Ra for the Material H13

Exp. No.	WT	WF	T on	T off	SV	IP				
	A	B	C	D	E	F	MRR	S/N ratio	Ra(μm)	S/N ratio
1	8	7	115	40	20	140	10.85	20.71	1.661	-4.407
2	8	7	120	50	40	170	6.504	16.26	2.918	-9.301
3	8	7	125	60	60	200	4.195	12.45	1.864	-5.407
4	8	8	115	40	40	170	8.162	18.24	4.058	-12.166
5	8	8	120	50	60	200	5.31	14.5	2.475	-7.872
6	8	8	125	60	20	140	6.534	16.3	2.748	-8.779
7	8	9	115	50	20	200	6.504	16.26	4.173	-12.409
8	8	9	120	60	40	140	3.731	11.44	1.844	-5.317
9	8	9	125	40	60	170	11.08	20.89	3.936	-11.902
10	10	7	115	60	60	170	1.984	5.95	1.611	-4.144
11	10	7	120	40	20	200	15.94	24.05	3.526	-10.945
12	10	7	125	50	40	140	8.745	18.84	1.638	-4.285
13	10	8	115	50	60	140	3.208	10.12	1.528	-3.681
14	10	8	120	60	20	170	5.044	14.06	3.061	-9.717
15	10	8	125	40	40	200	16.27	24.23	3.729	-11.431
16	10	9	115	60	40	200	2.872	9.164	1.911	-5.624
17	10	9	120	40	60	140	8.498	18.59	2.835	-9.05
18	10	9	125	50	20	170	10.81	20.68	4.979	-13.942

5.1 Analysis of Material Removal Rate Values for H13 Tool Steel

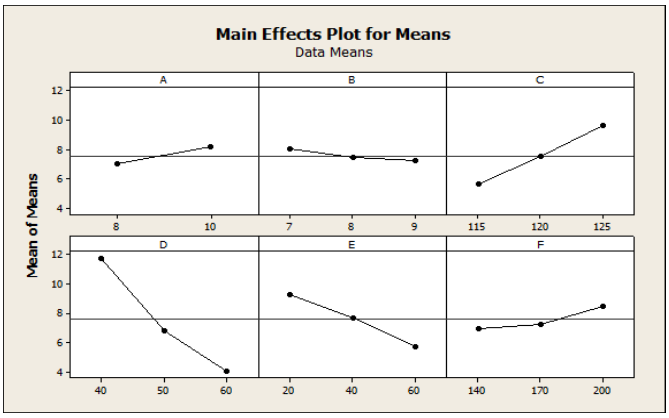

Figure 4: Effects of Process Parameters on MRR for H13 Tool Steel

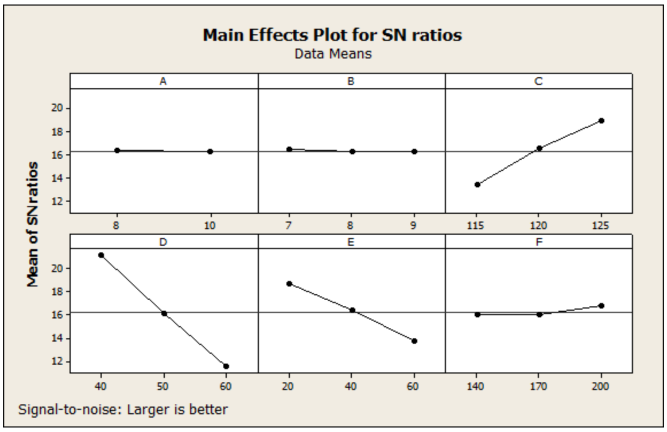

Figure 5: Effects of Process Parameters on MRR for H13 Tool Steel (S/N Data)

The Fig 5 concluded that Parameters Wire Tension (A) and Wire Feed(B) were not highly contribute in MRR whereas by increasing the value of parameter Pulse ON Time (C) and Peak current (F) the MRR also increased & by increasing the value of parameter Pulse Off Time (D) & Servo Voltage (E) the MRR decreased and this shows that A1, B1, C3, D1, E1 and F3 are the optimum factors.

η_{opt}=m+(mA1-m)+(mB1-m)+(mC3-m)+(mD1-m)+(mE1-m)+(mF3-m)
As here m = 16.263

Now by using the above relation and by putting the required values

$\eta_{opt} = 26.74$
$y_{opt}^2 = 1/10^{-\eta opt/10}$
$y_{opt} = 21.72\ mm^3/min$

Now the above value of MRR was theoretical and also the above set of optimum factors not present in the used array table so to find out the practical value of MRR at above optimum factors an experiment was done on the workpiece and through this experiment the required corresponding value is 22.21mm^3/min.

Table 6: Analysis of Variance for S/N ratios of MRR for H13

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC(%)
A	1	0.108	0.108	0.108	1.8	0.229	0.0245
B	2	0.132	0.132	0.066	1.1	0.393	0.02994
C	2	90.862	90.862	45.431	753.31	0.000	20.6124
D	2	274.153	274.153	137.077	2272.91	0.000	62.1927
E	2	72.815	72.815	36.4075	603.68	0.000	16.5184
F	2	2.379	2.379	1.1895	19.73	0.002	0.53969
Residual error	6	0.362	0.362	0.06033			0.08212
Total	17	440.812					

Table 7: Analysis of Variance for Means of MRR for H13

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
A	1	6.115	6.115	6.115	4.860	0.070	2.072
B	2	2.052	2.052	1.026	0.820	0.486	0.695
C	2	48.250	48.250	24.125	19.180	0.002	16.350
D	2	184.404	184.404	92.202	73.300	0.000	62.487
E	2	38.345	38.345	19.173	15.240	0.004	12.994
F	2	8.393	8.393	4.197	3.340	0.106	2.844
Residual error	6	7.547	7.547	1.258			2.557
Total	17	295.107					

Table 8: Response Table for Signal to Noise Ratios of MRR for H13
Larger is better

Level	A	B	C	D	E	F
1	16.34	16.38	13.41	21.12	18.68	16
2	16.18	16.24	16.48	16.11	16.36	16.01
3		16.17	18.9	11.56	13.75	16.78
Delta	0.16	0.21	5.49	9.56	4.92	0.78
Rank	6	5	2	1	3	4

Table 9: Response Table for Means of MRR for H13

Level	A	B	C	D	E	F
1	6.986	8.036	5.596	11.8	9.279	6.927
2	8.152	7.421	7.504	6.846	7.713	7.264
3		7.25	9.605	4.06	5.713	8.515
Delta	1.166	0.786	4.009	7.74	3.566	1.587
Rank	5	6	2	1	3	4

5.2 Analysis of Surface Roughness Values for H13 Tool Steel

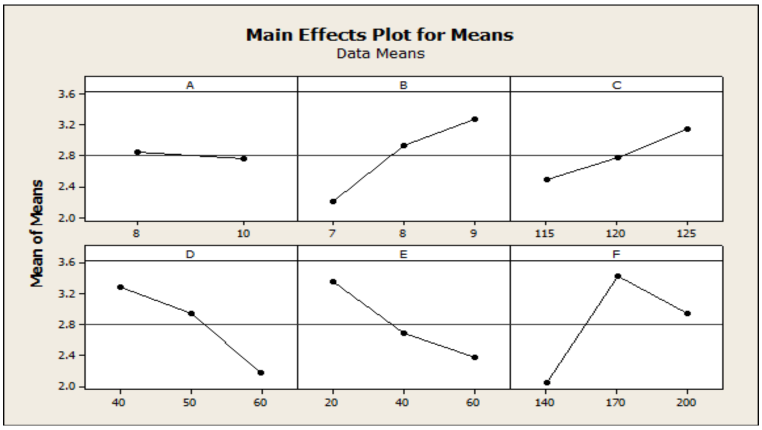

Figure 6: Effects of Process Parameters on Surface Roughness for H13 Tool Steel

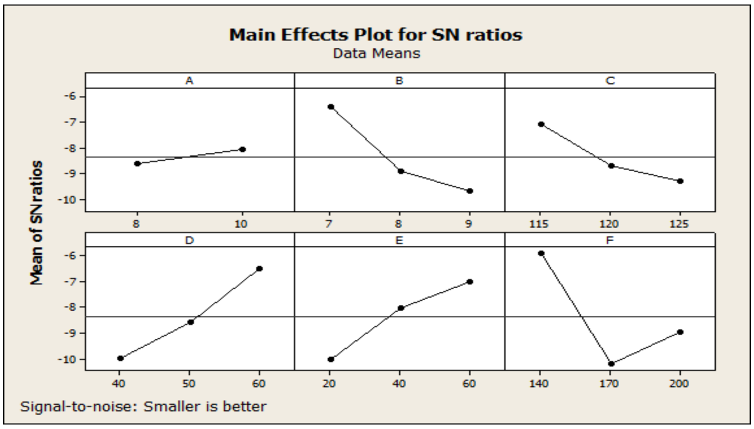

Figure 7: Effects of Process Parameters on Surface Roughness for H13 Tool Steel

Table 10: Analysis of Variance for S/N ratios of Ra for H13

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
A	1	1.249	1.249	1.249	0.48	0.514	0.65157
B	2	35.619	35.619	17.8095	6.85	0.028	18.5815
C	2	15.852	15.852	7.926	3.05	0.122	8.26956
D	2	36.911	36.911	18.4555	7.1	0.026	19.2555
E	2	28.44	28.44	14.22	5.47	0.044	14.8364
F	2	58.013	58.013	29.0065	11.15	0.010	30.2638
Residual error	6	15.607	15.607	2.60117			8.14175
Total	17	191.691					

Table 11: Analysis of Variance for Means of Ra for H13

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
A	1	0.041	0.041	0.041	0.170	0.696	0.213
B	2	3.626	3.626	1.813	7.430	0.024	18.739
C	2	1.308	1.308	0.654	2.680	0.147	6.762
D	2	3.940	3.940	1.970	8.070	0.020	20.366
E	2	3.034	3.034	1.517	6.220	0.034	15.681
F	2	5.934	5.934	2.967	12.160	0.008	30.669
Residual error	6	1.464	1.464	0.244			7.568
Total	17	19.347					

Table 12: Response Table for Signal to Noise Ratios of Ra for H13
Smaller is better

Level	A	B	C	D	E	F
1	-8.618	-6.415	-7.072	-9.984	-10.033	-5.92
2	-8.091	-8.941	-8.7	-8.581	-8.021	-10.195
3		-9.707	-9.291	-6.498	-7.009	-8.948
Delta	0.527	3.393	2.219	3.486	3.024	4.276
Rank	6	3	5	2	4	1

Table 13: Response Table for Means of Ra for H13

Level	A	B	C	D	E	F
1	2.853	2.203	2.49	3.291	3.358	2.042
2	2.757	2.933	2.776	2.952	2.683	3.427
3		3.28	3.149	2.173	2.375	2.946
Delta	0.096	1.077	0.659	1.118	0.983	1.385
Rank	6	3	5	2	4	1

The Fig. 6 concluded that by increasing the parameters wire Tension (A), Pulse off time (D) & Servo voltage (E) the value of Ra decreased whereas by increasing the Value of Parameters Wire Feed (B), Pulse ON Time (C) & Peak current (F) the value of Ra increased and this shows that A2, B1, C1, D3, E3 and F1 are the optimum factors.

η_{opt}=m+(mA2-m)+(mB1-m)+(mC1-m)+(mD3-m)+(mE3-m)+(mF1-m)
As here m = -8.355

Now by using the above relation and by putting the required values

$\eta_{opt} = 0.77$
$y_{opt}^2 = 10^{-\eta opt/10}$
$y_{opt} = 0.92\mu m$

Now the above value of Ra was theoretical and also the above set of optimum factors not present in the used array table so to find out the practical value of Ra at above optimum factors an experiment was done on the workpiece and through this experiment the required corresponding value is 0.89 µm.

Conclusions

(a) Conclusion for MRR

1) The pulse on time parameter has direct effect on the material removal rate, as the pulse on time increased the material removal rate also increased.
2) When peak current is increased the material removal rate increased.
3) When the pulse off time is increased the material removal rate decreased.
4) When servo voltage increased the material removal rate decreased.
5) The parameter wire tension (WT) has small effect on the material removal rate.
6) The parameter wire feed (WF) has small effect on the material removal rate.

(b) Conclusion for Surface Roughness

1) When parameter pulse on time increased the value of Surface Roughness increased.
2) When the pulse off time increased the value of Surface Roughness is decreased.
3) The value of Surface Roughness is decreased by increasing servo voltage.
4) When parameter peak current increases the value of Surface Roughness increased.
5) When wire tension increased the value of Surface Roughness is decreased.
6) 6. When wire feed increased the value of Surface Roughness is increased.

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