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Optimization of Process Parameters on Performance Measure of WEDM of SS 410

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Abstract: Wire Electric Discharge machining is widely and extensively used in the machining materials of complicated and intricate shapes with precision which are not possible with conventional machining methods. The stainless steel 410 has been considered in the present work. The experimentation has been completed by using Taguchi's L_9 orthogonal array with different levels of input parameters. The aim of the present work is to optimize the parameters of WEDM process by considering the effect of input parameters viz. T_{on}, T_{off}, WF and WT. Experiment have been conducted with these parameters in three different levels data related to process responses viz. Material Removal Rate (MRR), Surface Roughness (Ra) have been considered and obtained for the each run of the experiment. Thus this paper shows the effect of various WEDM process parameters such as T_{on}, T_{off}, WF, WT on different process responses such as MRR and Ra. The settings of process parameters were determined by Taguchi's design of experiment. Signal to Noise ratio (S/N) and analysis of variance (ANOVA) were used to analyse the effect of selected process parameters on MRR and Ra. And to identify the optimum cutting parameters setting.Regression analysis is also used for determining the predicted values of MRR and Ra for comparing them with actual results. The Taguchi Technique was used for design of experiment so that with minimum number of experiments, the complete problem can be solved as compared to full factorial design.

Keywords: WEDM, Taguchi's Method, SS 410, Orthogonal Array, Process Parameters, MRR, Ra, S/N ratio, ANOVA, Regression Analysis

1. Introduction

As the world is advancing forth technically in field of space research, missile and nuclear industry; very complicated and precise components having some special requirements are demanded by these industries. The challenge is taken by the new developments taking place in manufacturing field. Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing which are nearly impossible to be machined by the conventional machining process. Hence, non-conventional machining methods including electron beam machining, laser beam machining, electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine and intricate shaped materials. WEDM process transforms electrical energy to thermal energy for cutting materialswith the use of a thin wire as an electrode and the distilled water is used as the dielectric fluid in WEDM process. By using this process, alloy steel, aerospace materials and intricate shaped materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. WEDM is considered as distinctive acquisition as traditional EDM process, which uses an electrode to initialize the sparking process. The wire cut uses a very thin wire 0.05to 0.3 mm in diameter as an electrode and machines a workpiece with electric discharge like band saw by moving either the work piece or wire.

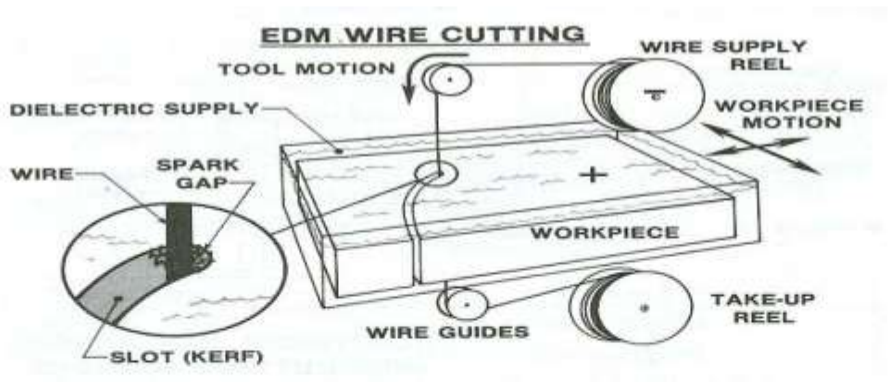

Figure-1: Principle of WEDM

WEDM is advance adoption of conventional electric discharge machining (EDM) which uses an electrode to initialize the sparking process. The electrode is in form of thin wire and transforms electrical energy to thermal energy. Thus heat produced is cause of cutting of materials. In this the wire electrode made of brass, copper and tungsten of diameter 0.05to 0.3 mm is continuously travelling during the process and can achieve very small corner radii. This process eliminates mechanical stress during machining as material is eroded ahead of wire. So no direct contact between workpiece and wire takes place. In WEDM process very precise and wear resistant surface can be produced. Hard and tough materials like alloy steels, conductive materials and ceramics can be machined with WEDM. The machine also specialize in cutting complex contours or fragile geometries that would be difficult to be produced using conventional cutting methods.

2. Literature Review

For obtaining the better parametric settings, lot of experiments has been performed in the engineering design. The WEDM processes are having several performance characteristics like Metal Removal Rate, Surface roughness, Kerf width; Dimensional error etc. The optimal parametric settings with respect to different performance characteristics are different. Some of the research contributions to cite are: Singh and Garg [1] studied the effects of process parameters on MRR in WEDM, and it was found that, when pulse on time and peak current increase MRR also increase but MRR decrease with the increase in T_{off} and servo voltage. Kanlayasiri and Boonmung [2] presented the effect of process parameters of WEDM on Ra of newly developed DC 53 die steel of width, length, and thickness 27, 65 and 13 mm, respectively. The machining variables included pulse-on time, pulse-off time, pulse-peak current, and wire tension.

The variables affecting the surface roughness were identified using ANOVA technique.Mahapatra and Patnaik [3] shows in their investigation the effects of six factor include, pulse on time, pulse frequency, wire speed, wire tension, discharge current, and dielectric flow rate on surface roughness and material removal rate and it was found that factors like discharge current, pulse duration =, dielectric flow rate and their interactions play significant role in surface roughness and material removal rate.Lin and Lin [4] presented a new approach for the optimization of the EDM process with numerous performance characteristics based on the orthogonal array with the grey relational analysis. Optimal grey relational analysis was used as the performance index with orthogonal array by determining the optimal machining parameters. The machining process parameters viz. pulse duration, open discharge voltage, discharge current, work piece polarity, duty factor, and dielectric fluid were optimizedwith response process parameters including MRR, Ra and EWR.Puri and Bhattacharyya [5] hired Taguchi methodology which involves thirteen control factors with 3 levels for an orthogonal array L_{27} to observe the important parameters that affect the different machining measures which aresurface roughness values, average cutting speed, and the geometrical defect which is caused by wire lag..

Huang and Liao [6] presented the use of grey relational and S/N ratio analysis, for determining the optimal parameters setting of WEDM process. The results showed that the MRR and surface roughness are easily influenced by the table feed rate and pulse on time. Ramakrishnan and Karunamoorthy [7] considered three response characteristics, e.g. MRR, SR and wire wear ratio (WWR) for a WEDM process and determined the optimal process settings by optimization of multiple response signal-to-noise (MRSN) ratio, which is the logarithmic transformation of the sum of the weighted normalized quality loss of individual response variable. Chiang and Chang [8] investigated the study for the optimization of the WEDM process of Al2O3 particle reinforced material with two performance characteristics, e.g. SR and MRR, based on the grey relational analysis. Jaganathan et al. [9] investigated the effects of different input parameters on MRR and SR and got the result using Taguchi optimization technique that voltage, pulse width, and wire speed is critical input parameters. S.B. Prajapti and Patel [10] concluded T_{on} and T_{off} put impacts on cutting rate and surface roughness critically machining process parameters on AISI A2 tool steel in WEDM.

3. Experimental Work and Procedure

In the present paper, Taguchi method is employed for the optimization of selected process parameters viz. Pulse on time, Pulse off Time, Wire Feed and Wire Tension on the machining performance measure viz. Material Removal Rate and Surface Roughness. The experiments were performed according to Taguchi’s Design of Experiments.

3.1 Work Material

The material of the workpiece selected in the present investigation was Stainless Steel 410.The stainless steel plate of size 235mm×100mm×8.25mm has been used as a workpiece material for the present experiment. Stainless steel 410 is one such material which can be used in applications of Rifle barrels, cutlery, and jet engine parts. SS 410 is the basic Martensitic type. It is the general purpose corrosion and heat resisting chromium stainless steel. The chemical composition of the SS 410 includes:

Constituent	% Composition
Carbon	0.08-0.15
Manganese	1 max.
Phosphorus	1 max.
Sulphur	0.030 max.
Silicon	1 max.
Chromium	11.50-13.50

3.2 Cutting tool (Electrode)

In this work wire electrode of brass having standard diameter 0.25 mm is used as electrode.

3.3 Design of Experiments

In the present work, the experiments were designed by using Taguchi's technique. Dr. Genichi Taguchi a scientist from Japan developed a technique based on the orthogonal array of the experiments so that the entire parametric space could be studies with minimum number of experiments. In the present research paper four input process parameters selected such as Pulse on time, Pulse off Time, Wire Tension and Wire feed. For all of them three different levels was selected. So based on the number of control factors and their levels, Taguchi's L_9(3^4) Orthogonal array was selected. The below shown Table 1 shows the various levels of control factors and Table 2 shows the experimental plan with assigned value.

Table-1: Levels of various control factors

Control factors		**Levels**		
		I	**II**	**III**
A	Pulse on time	121	126	131
B	Pulse off time	50	55	60
C	Wire feed	4	5	6
D	Wire tension	7	9	11

Table-2: Experimental plan with assigned value

Run	Control factors and levels			
	Pulse on time	Pulse off time	Wire feed	Wire tension
1	121	50	4	7
2	121	55	5	9
3	121	60	6	11
4	126	50	5	11
5	126	55	6	7
6	126	60	4	9
7	131	50	6	9
8	131	55	4	11
9	131	60	5	7

3.4 Experimental Work

The present investigation of the experiments were experiments were accomplished on an Electronica Sprintcut WEDM machine. Following steps were followed in the cutting operation. The wire was made vertical with the help of verticality block. The work piece was mounted and clamped on the work table. A reference point on the work piece was set for setting work co-ordinate system (WCS). The programming was done with the reference to the WCS. The reference point was defined by the ground edges of the work piece. The basic parts of the Wire Electric Discharge Machining consists of wire feed spool, work head, water tank, display screen, power supply, electrode etc. The Electronica Sprintcut WEDM machine used in the present investigation is shown in the below figure 2.

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Figure 2: Wire cut Electric Discharge Machine

In the below figure 3 the setup of the workpiece on the work head during machining is shown.

Figure 3: Clamping of the workpiece on work head of WEDM

Table-3: Parameters of Electronica Sprintcut CNC WEDM

Control factors	Symbols
Pulse on time	A
Pulse off time	B
Wire feed	C
Wire tension	D

Fixed parameters	
Wire used	Brass wire of diameter 0.25mm
Height of the workpiece	8.25 mm
Flushing pressure	1
Servo feed	2150
Work material	SS 410

3.5 Selected process responses

In the present investigation the two process responses are selected to calculate in the run of the experiment against the control factor settings. These two process responses are calculated in the presented work are Material Removal Rate and Surface Roughness.
The MRR is calculated by the following expression
MRR= $(W_b - W_a)/(T_m \times \rho)$ (mm3/sec)
Where W_b is the weight before machining
W_a is the weight after machining
T_m is the machining time
and ρ is the density of the material

And the Surface roughness is measured by the Mitutoyo suftest SJ-210 surface roughness tester.

4. Results and Discussion

The results of the present work obtained are analysed using S/N Ratios, Response table and Response Graphs with the help of Minitab software. Minitab is a computer program software designed to perform basic and advanced statistical functions. It is a popular statistical analysis package for scientific applications, in particular for design and analysis of experiments. In this experimental results are analysed and Regression equation is developed to predict the metal removal rate and surface roughness and graphs.

Table-5 Results Table

S.No.	T_{on} (µs)	T_{off} (µs)	WF (m/min)	WT (gms)	MRR (mm^3/sec.)	Ra (µm)
1	121	50	4	7	3.1465	4.12
2	121	55	5	9	2.5777	3.74
3	121	60	6	11	2.1138	3.84
4	126	50	5	11	3.9974	4.54
5	126	55	6	7	3.3491	4.04
6	126	60	4	9	2.9151	4.42
7	131	50	6	9	4.1569	4.62
8	131	55	4	11	4.2781	4.88
9	131	60	5	7	4.1757	4.40

4.1 Selection of the Best Parameter Selection

Taguchi Analysis: MRR and Ra versus T_{on}, T_{off}, wire feed and wire tension is carried out and average of each level is the parameter for raw data is given in table-6 for MRR and in table-7 for Ra and average of each level in terms of S/N ratios are given in table-8 for MRR and in table-9 for Ra and response graphs for means is shown in figure-5 and figure-6 and S/N ratios are shown in figure-7 and figure-8 respectively for MRR and Ra.

Table-6 Response table for S/N ratios for MRR

Larger is Better

Level	T_{on}	T_{off}	Wire feed	Wire tension
1	8.227	11.456	10.625	10.657
2	10.609	10.449	10.892	9.964
3	12.472	9.403	9.792	10.338
Delta	4.244	2.053	1.100	0.992
Rank	1	2	3	4

Table-7 Response table for means for MRR

Level	T_{on}	T_{off}	Wire feed	Wire tension
1	2.613	3.767	3.447	3.557
2	3.421	3.402	3.584	3.217
3	4.204	3.068	3.207	3.463
Delta	1.291	0.699	0.377	0.341
Rank	1	2	3	4

Table-8 Response table for S/N ratios for Surface Roughness

Smaller is better

Level	T_{on}	T_{off}	Wire feed	Wire tension
1	-11.81	-12.91	-12.99	-12.43
2	-12.73	-12.45	-12.49	-12.55
3	-13.31	-12.49	-12.37	-12.87
Delta	1.50	0.46	0.62	0.43
Rank	1	3	2	4

Table-9 Response table for means for Surface roughness

Level	T_{on}	T_{off}	Wire feed	Wire tension
1	3.900	4.427	4.473	4.187
2	4.333	4.220	4.227	4.266
3	4.633	4.220	4.167	4.420
Delta	0.733	0.207	0.307	0.233
Rank	1	4	2	3

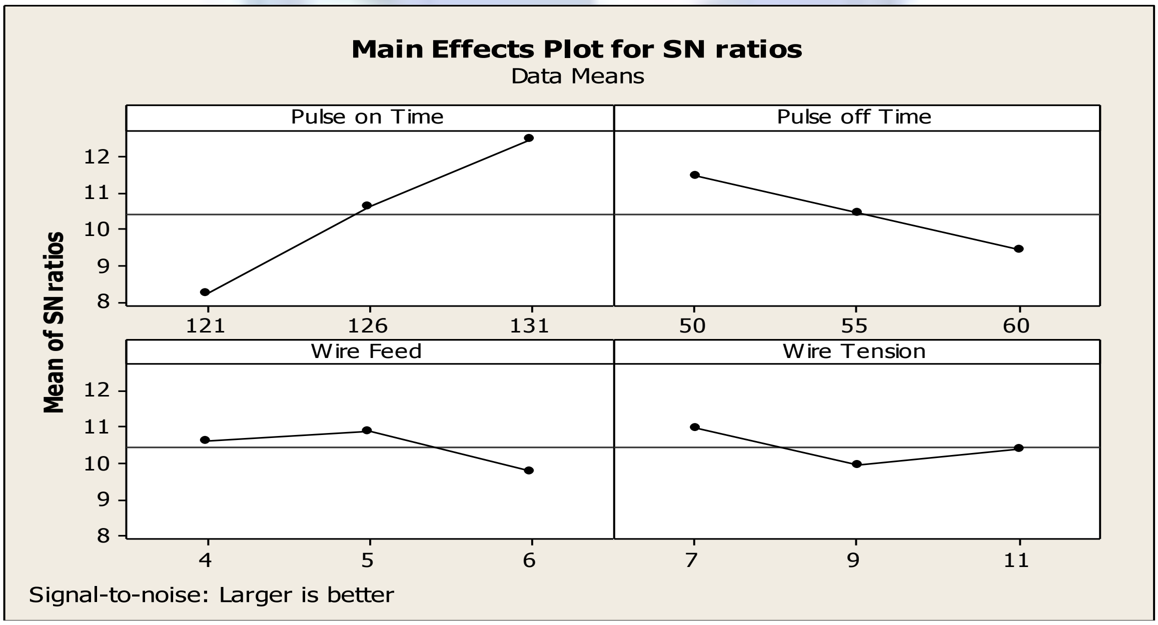

Figure-5 Response graphs for S/N ratio for MRR

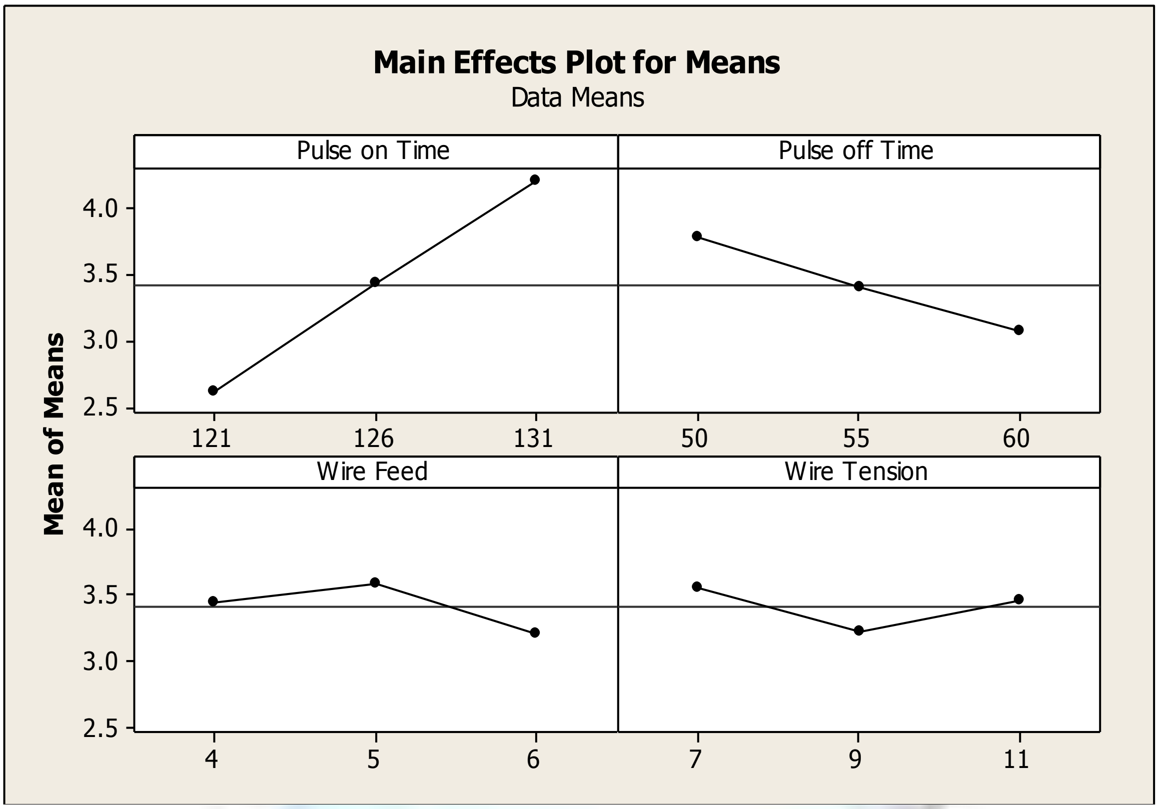

Figure -6 Response graph for means for MRR

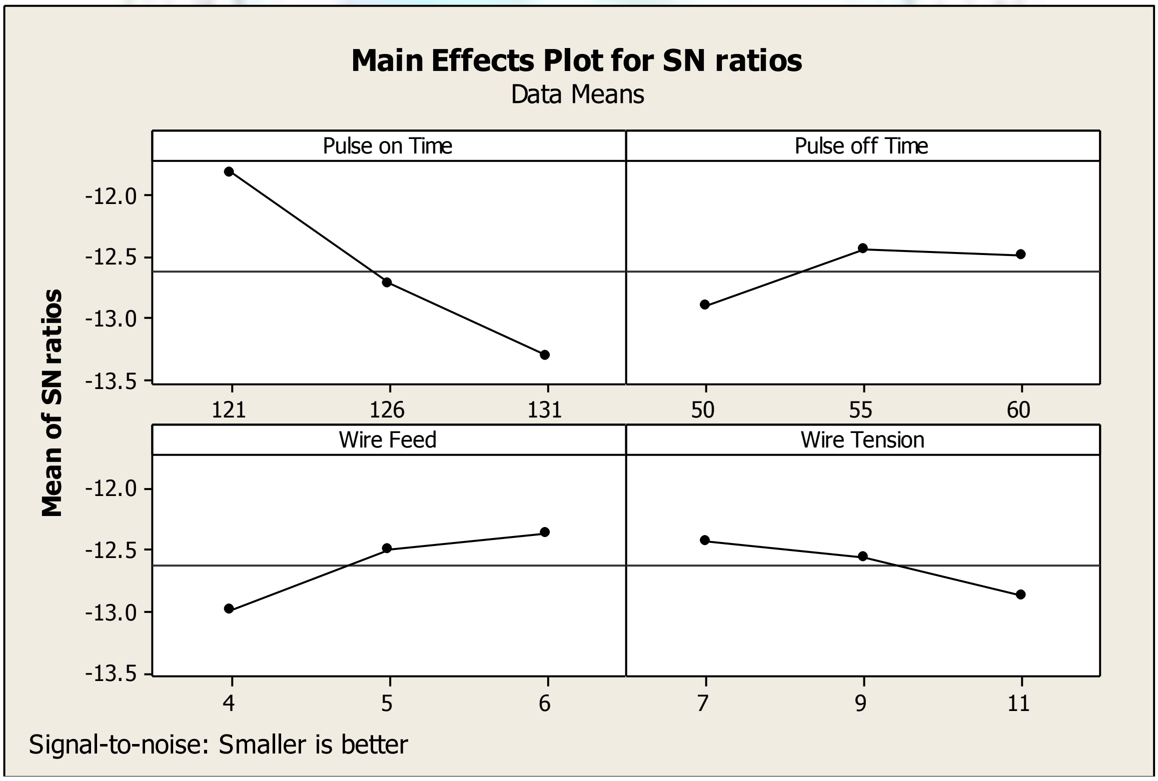

Figure -7 Response graph for S/N ratios for Ra

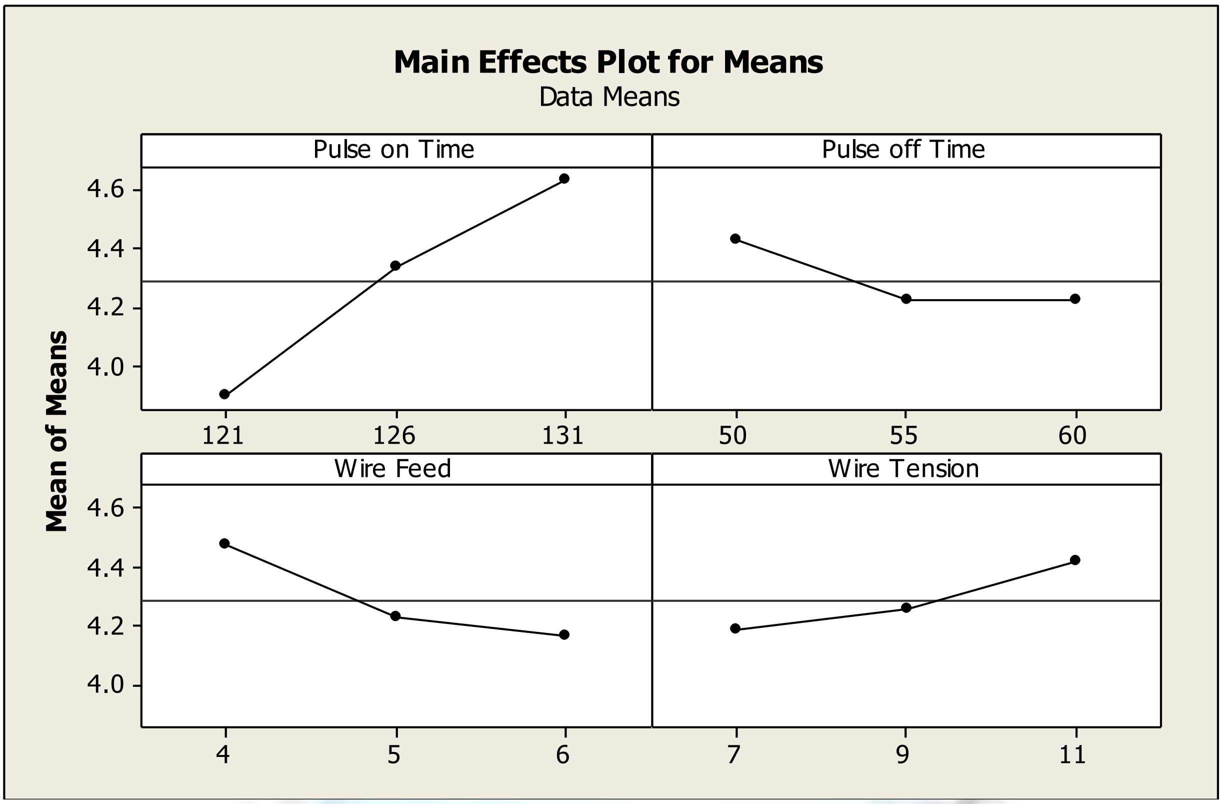

Figure-8 Response graph for means for Ra

4.2 Development of Regression equation

The objective of multiple regression analysis is to construct a model that explains as much as possible, the variability in a dependent variable, using several independent variables.

The regression equation for MRR is
MRR = - 12.0 + 0.159 Pulse on Time - 0.0699 Pulse off Time - 0.120 Wire Feed
- 0.0235 Wire Tension

The regression equation for surface roughness is
Ra = - 3.57 + 0.0733 Pulse on Time - 0.0207 Pulse off Time - 0.153 Wire Feed
+ 0.0583 Wire Tension
With the help of Regression equation the predicted values of MRR and Ra is estimated and their deviation is tabulated. It is observed that the predicted values are closer to experimental values as in Table-9 &10.

Table-9 Actual and Predicted value of MRR

Predicted MRR	Actual MRR	Deviation
3.0995	3.1465	-0.047
2.5830	2.5777	0.0053
2.0665	2.1138	-0.0473
3.6805	3.9974	-0.3169
3.3050	3.3491	-0.0441
3.1485	2.9151	0.2334
4.4025	4.1599	0.2426
4.2460	4.2781	-0.0321
3.8705	4.1757	-0.3052

Table -10 Actual and Predicted value of Ra

Predicted Ra	Actual Ra	Deviation
4.0604	4.12	0.0596
3.9205	3.74	-0.1805
3.9186	3.84	-0.0786
4.5071	4.54	0.0329
4.0174	4.04	0.0226
4.3365	4.42	0.0835
4.6040	4.62	0.0160
4.92231	4.88	-0.0431
4.6666	4.40	-0.2666

Conclusions

After studying the results and discussions the following conclusions made regarding the present work.

1. The better parameter setting is Pulse on time- 131 µs, Pulse off time-50 µs, Wire feed-4m/min and Wire Tension- 11 m/min for maximum MRR.
2. The better parameter setting for minimum Surface Roughness is Pulse on time-121µs, Pulse off time-55µs, wire feed-5m/min and Wire tension-9 gms.
3. The order strength parameters are found from response table for MRR is T_{on}, T_{off}, Wire feed and Wire tension.
4. The order strength parameters are found from response table for S/N ratio for Surface Roughness is T_{on}, Wire feed, Wire tension and T_{off} and for mean for Ra is T_{on}, Wire tension, T_{off} and Wire feed.
5. After performing the experiments it is concluded that with the increase in Pulse on time and Pulse off time the MRR in the present work increase and with the increase of WF and WT the MRR decreases for SS 410.
6. Pulse on time highly effects the surface roughness.

Future Scope

1. The present work is made on the SS 410. So the procedure can be extended for the other grades of stainless steels and composites with different techniques
2. The work also can be performed by changing the process parameters and process responses.
3. The work also can be done with the use of different techniques like RSM, GRA etc.

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