Optimization of Process Parameters Influencing MRR, Surface Roughness and Electrode Wear During Machining of Titanium Alloys by WEDM

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ABSTRACT - Wire-cut Electrical Discharge Machining (WEDM) is extensively used in machining of conductive materials producing intricate shapes with high accuracy. This study exhibits that WEDM process parameters can be altered to achieve betterment of Material removal rate(MRR),Surface Roughness (SR) and Electrode Wear**.** The objective of our project is to investigate and optimize the potential process parameters influencing the MRR, SR and Electrode Wear while machining of Titanium alloys using WEDM process. This work involves study of the relation between the various input process parameters like Pulse-on time(T_{on}), Pulse-off time(T_{off}), Pulse Peak Current(IP), Wire material and Work piece material and process variables. Based on the chosen input parameters and performance measures L-16 orthogonal array is selected to optimize the best suited values for machining for Titanium alloys by WEDM.

Keywords - T_{on} ,T_{off},IP,MRR, SR, Electrode Wear and orthogonal array.

1.INTRODUCTION

Recently, unconventional machining is being established well and is used by the component manufacturer as a manufacturing method. Non-conventional is not involved with the high force and itsa green process. The process doesn't deal with the metal chip and only water is used as an electrode.Wire-EDM as a precision cutting technology is possible to fabricate from a small range of product to a large size of component. All types of good conductivity metal such as mild steel and copper are possible to be cut using wire-EDM. However, machine setting varies for each type of metals. So, certain parameters need to be clearly defined for each of materials.The setting is easy tuned for a straight line and become more difficult for the curve or part which is involving an angle. Rough cutting operation in wire EDM is treated as challenging one because improvement of more than one performance measures viz.
Metal removal rate , Surface Roughness & Electrode Wear Rate(EWR) are used as parameters to obtain precision work. In this research a path to determine parameters setting is proposed. Using orthogonal array method, significant machining parameters affecting the performance measures are identified as pulse peak current, pulse on time, and pulse off time. Using the plots of Signal to noise ratio, the effect of each control factor on the performance measure is studied separately. The study explains that the WEDM process parameters can be adjusted so as to achieve maximum metal removal rate and reduced electrode wear rate and surface Roughness.

Atul Kumaret al. [1] investigated influences of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel of width, length, and thickness 27, 65 and 13 mm, respectively. K.H.Hoet al [2]found WEDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as metals, alloys, some ceramic materials and even graphite.

Y.S Liao et al[3] investigated that WEDM machines have endorsed the pulsegenerating circuit using low power for high power and ignition for machining. Nonetheless, it is unsuitable for finishing process since the energy produced by the high voltage sub circuit is very high to obtain a covet fine surface, no consideration is given to the fewer pulse-on time is assigned. As newer and more exotic materials are developed, and more complex shapes are presented, conventional machining operations will continue to reach their limitations and the increased use of wire EDM in manufacturing will continue to grow at an accelerated rate[4]. NihatTosun et.al [5] investigated on the effect and optimization of machining parameters on the kerf (cutting width)and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations.

Hewidy et al [6] developed themathematical models correlating the various WEDM machining parameters such as water pressure,peak current, wire tension and with metal removal rate, wear ratio,duty factor and surface roughness based on the response surface methodology.Mahapatra [7] studied the relationships between various control factors and responses like SF,MRR and kerf by means ofnonlinear regression analysis, resulting in a valid mathematical model. The study demonstrates that the WEDM process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously.

Sarkar et al.,[8](2005, 2006) produced a technology guideline for optimum machining of gamma titanium aluminide based on Pareto-optimal solutions. Additionally, they calculated the wireoffset value and used it as input parameter to enhance the dimensional accuracy of the product.

By applying multi-response S/N (MRSN) ratio technique, Ramakrishnan&Karunamoorthy (2006,2008)et al [9] reported optimal setting for WEDM of tool steel and inconel 718.Anand et al[10]usedafractionalfactorialexperimentwithanorthogonalarraylayouttoobtainthemostdesirableprocessspecificationforimprovingtheWEDMdimensionalaccuracyandsurfaceroughness.Miller et al, [11] in their paper have discussed about wire electrical discharge machining (WEDM) of cross-section with minimal thickness and compliant mechanisms is measured. This was backed by findings from SEM micrographs of EDM debris , subsurface, surface.

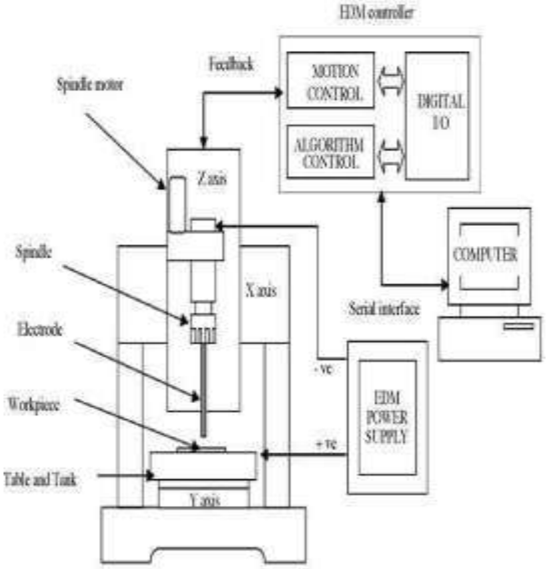
Konda et al [12] classified the various potential factors affecting the WEDM performance and in addition,they applied the Design of experiments(DOE) technique to study and optimize the possible effects of parameters during process design and development.

C. Bhaskar Reddy et.al, [13] have investigated for the best parameter selection to obtain maximum Metal removal rate (MRR),Electrode wear rate(EWR) and better surface roughness (SR) by conducting the experiment on CONCORD DK7720C four axes CNC Wire Electrical Discharge Machining of P20 die tool steel with molybdenum wire of 0.18mm diameter as an electrode. From the literature, several researchers have applied the Taguchi method and used to optimize the performance parameters in WEDM process. In the Present work Ti alloy is considered for calculating the output parameters likesurface roughness,material removal rate and (EWR)electrode wear rate using Orthogonal Array method .

2.EXPERIMENTAL SETUP

The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of M.S.K Tools Ltd, Chennai, India. The WEDM machine tool (Figure 2.1) has the following specifications

Design	Fixed column with 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), 0.15, 0.20 mm (Optional)
Generator	ELPULS-40 A DLX
Controlled axes	X Y, U, Vsimultaneous
Interpolation	Linear & Circular
Least input increment	0.0001mm
Input Power supply	3 phase, AC 415 V, 50 Hz
Connected load	10 KVA



3.WORKPIECEMATERIAL SELECTION

Due to the different melting point, evaporation and thermal conductivity, different materials show different surface quality and MRR at the same conditions of machining.Titaniun(Grade 5 & Grade 2)is the workpiece material which is used in this experiment.The titanium plate of 125mm x 100mm x 3mm size has been used as a work piece material and a profile of 5mm x 5mm x 2mm is been cut with the wire(Brass and Brass coated Nickel) traversing the through the kerf made and the performance analysis of output parameters with respect to input parameters is measured.

- Grade 5, also known as Ti6Al4V, Ti-6Al-4V or Ti 6-4(C-0.036,Al-6.30,V-3.99,Ti-89.31) is the most commonly used alloy. Pure titanium undergoes an allotropic transformation from the hexagonal close-packed alpha phase to body-centered cubic beta phase at a temperature of 882.5°C (1620.5°F).

- Grade 2(C-0.008,Fe-0.04,Ti-99.83) is otherwise known aspure titanium undergoes an allotropic transformation from the hexagonal close-packed alpha phase to body-centered cubic beta phase at a temperature of 882.5°C(1620.5°F).Commercially pure, or CP, titanium is unalloyed. At service temperature, it consists of 100% hcp alpha phase.

4.METHODOLOGY

4.1 Taguchi Method

Taguchi, a Japanese scientist, developed a technique based on Orthogonal Array(OA) of experiments.Theassimilation of DOE with parametric optimization of the process can be accomplished in the Taguchi method. An OA gives a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios,that are logarithmic functions of the craved output, serve as an objective functions for optimization. It comforts to learn the whole parameter space with a small number (minimal experimental runs) of experiments. OA and S/N ratios are used to study the effects of control factors and noise factors and to determine the best quality characteristics for particular applications.

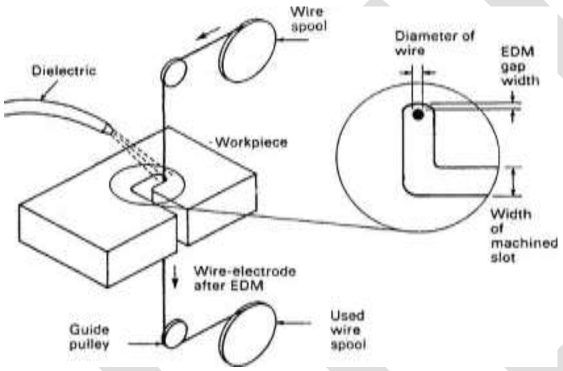


Fig.2. Principle of wire EDM

The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. However,Taguchi method was most suitable in the case to optimize single performance characteristics.

4.2Orthogonal array Method:

Orthogonal array testing is a black box testing technique that is a efficient, methodogical and statistical way of software testing.It is usally preferred when the number of inputs to the system is small, but very large to permit for exhaustive testing of each possible input to the systems. Orthogonal approach guarantees a pair wise coverage of all Variables.Orthogonal array method has an application in user interface testing, configuration testing and performance testing.Orthogonal array testing guarantees testing the pairwise combination of all the selected variables. The net effects of organizing the experiment in such treatments is that the same piece of information is gathered in the minimum number of experiments.OA's are commonly represented as $L_{Runs}(Levels^{Factors})$ or Orthogonal Array(Runs, Factors, Levels, Strength) or **OA_{λ}(Runs(N); Factors(k), Levels(v), Strength(t))** is an N × k array on v symbols such that every N × t sub-array contains all tuples of size t from v symbols exactly λ times.

Runs (N) – Number of rows in the array, which translates into the number of Test Cases that will be generated.

Factors (k) – Number of columns in the array, which translates into the maximum number of variables that can be handled by the array.

Levels (v) – Maximum number of values that can be taken on by any single factor.

Strength (t) – The number of columns it takes to see all the possibilities equal number of times.

4.3Signal-to-Noise ratios (S/N ratio)

In the Taguchi method, the term "signal" denotes the desirable value (mean) for the output characteristic and the term "noise" represents the undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to estimate the quality characteristic deviating from the desired value (8-9). The S/N ratio η is defined as
1. Larger the Better:
S/N = -10 log (1/n)--------------------------(1)
2. Smaller the Better:
S/N = -10 log (1/n)-----------------------------(2)
Where n = no of repetition

4.4Material Removal Rate (MRR*)*

This is a production term usually measured in mm^3/s. Increasing the MRR will obviously get a part done quicker,but increasing the material removal rate is often accompanied by increases in tool wear, poor surface finishes. The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material. Therefore, the MRR for the WEDM operation is calculated as

MRR = (Wjb~Wja)
Whereas ,Wjb = Weight of workpiece before machining.
Wja = Weight of workpiece after machining.
t = Machining time
ρ = Density of Titanium grade-2 = 4.51*10-3 g/mm3
Density of Titanium grade-5 = 4.42*10-3 g/mm3 42
Wjb=[(Weight of the plate before machining)-[(Dia of Wire*Tickness of plate*Length of the Kerf)]/**( )**
Wja=[(Weight of plate before machining)+(Weight of the removed piece)]/(t*)

4.5Surface Roughness measurement

The surface roughness is measured using the surface tester SE-1200 measures roughness and evaluate parameters according to the following standards: ISO 4287, ISO 12085 (MOTIF or CNOMO), DIN, ASME, JIS. There are two storing modes available in surfcorder,they are Memo and statistics. With the Memo mode the measurements are stored, in order to display and/or print them. With the Statistics the measurements stored on a maximum of 12 parameters to perform various statisticanalysison graphs and histograms can be displayed or printed out. Initially the job whose surface roughness has to be tested is mounted on the V-block and then a motorized arm which holds the stylus moves along the vertical column.And finally as the stylus comes in contact with the surface of the job. The high resolute printer will provide the details about the surface roughness in a printed form.

4.6Electrode Wear Rate

The electrode wear rate is measured by using Digital VernierCaliper,where the diameter of the wire before machining is calculated is compared with the diameter of the wire after machining.

Electrode wear is not just a function of electrode properties,but is also a function of power supply settings. Electrode wear is the percentage ratio of the amount of electrode material lost from the electrode to the cavity corresponding to the input process parameters.

EWR = [Area of the electrode x Length of the Electrode]/t

5.SELECTION OF CUTTING PARAMETERS

5.1**Orthogonal Array Selector**

Orthogonal Array	**No .of Experiment**	**No. of factor**
L-4	4	3
L-8	8	7
L-9	9	4
L-12	12	11

L-16	16	15
L-16	**16**	**5**
L-18	18	8
L-25	25	16
L-27	27	13
L-32	32	31
L-32	32	10
L-36	36	23
L-36	36	16
L-50	50	12
L-54	54	26
L-64	64	63
L-64	64	21
L-81	81	40

Table 5.1 Orthogonal Array Selector Table

From this above array table, we have chosen the orthogonal array of L-16 since our No of factors is 5 are pulse on time, pulse off time, peak current, wire material, workpiece material [14]. Minitab 15 software was used for graphical analysis of the obtained data.

5.2 Level Values of Input Factor

S.NO	Control Factor	Symbol	Level 1	Level 2	Unit
1	Pulse-on time	A	115	120	µs
2	Pulse-off time	B	50	55	µs
3	Peak current	C	150	200	A
4	Wire material	D	Brass (0.25mm)[D1]	Brass coated Ni (0.25mm)[D2]	mm
5	Workpiece material	E	Grade-2 (E1)	Grade-5 (E2)	-

Table 5.2 Level Values of Input Factor

5.3 Selection from Array

Ex.No	A	B	C	D	E
1.	A_1	B_1	C_1	D_1	E_1
2.	A_1	B_1	C_1	D_1	E_2
3.	A_1	B_1	C_1	D_2	E_1
4.	A_1	B_1	C_1	D_2	E_2
5.	A_2	B_2	C_2	D_1	E_1
6.	A_2	B_2	C_2	D_1	E_2
7.	A_2	B_2	C_2	D_2	E_1
8.	A_2	B_2	C_2	D_2	E_2
9.	A_1	B_2	C_1	D_1	E_1
10.	A_1	B_2	C_1	D_1	E_2
11.	A_1	B_2	C_1	D_2	E_1
12.	A_1	B_2	C_1	D_2	E_2
13.	A_2	B_1	C_2	D_1	E_1
14.	A_2	B_1	C_2	D_1	E_2
15.	A_2	B_1	C_2	D_2	E_1
16.	A_2	B_1	C_2	D_2	E_2

Table 5.3 Selection from Array Table

To evaluate the effects of machining parameters on performance characteristic (MRR), and to identify the performancecharacteristic under the optimal machining parameters, a specially designed experimental procedure is required.

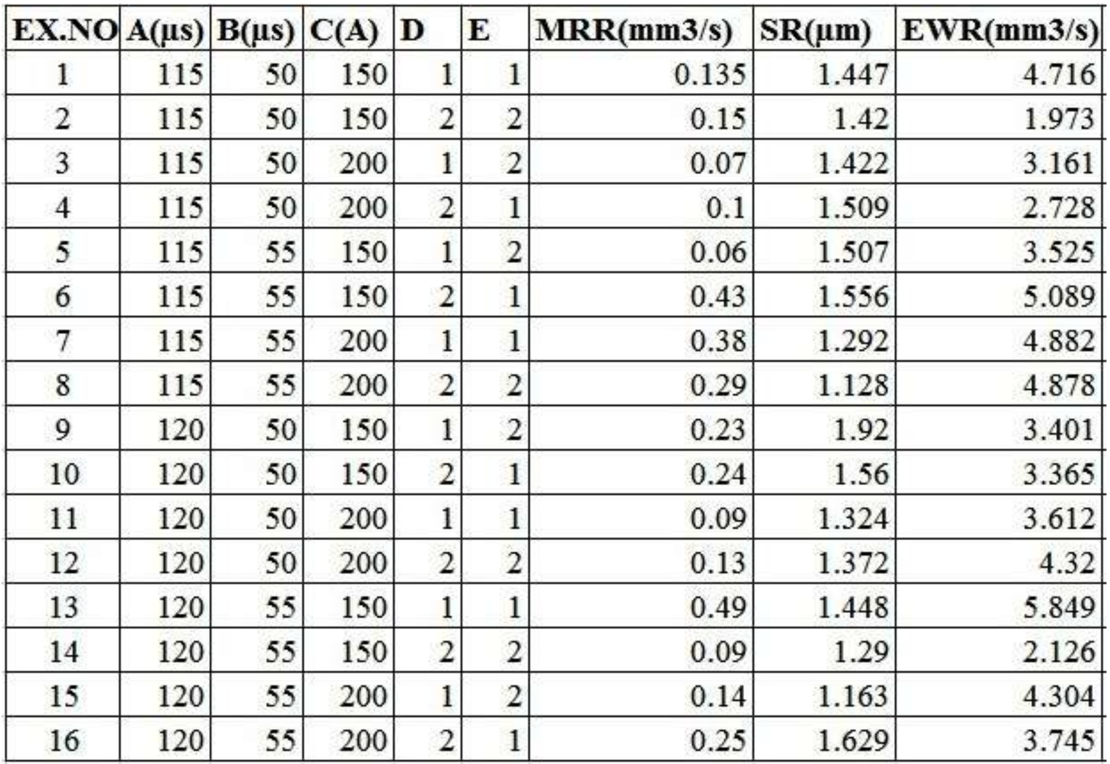
6.EXPERIMENTAL TESTING

Various experiments were performed to find how the output parameter varies with the variation in the input parameters. Theexperiments were performed in constant voltage mode of the WEDM.In the set of experiments Pulse on current is varied from 105 units to 129 units in the steps of 3 units, pulse off time (TOFF) is varied from 63 units to 39 units with regular decrement of 3 units, peak current (IP) is varied from 230 amp to 50 amp in the decrements of 20 amp.

In the first set of experiments,the fixed input variables are T_{on} =115;T_{off} = 50;IP = 150 are set and the corresponding MRR,SR,EWR are measured by machining Titanium(Grade 5 & 2) by brass and brass coated electrode wire.In the second set of experiments,the fixed input variables are T_{on} =120;T_{off} = 55;IP = 200 are set and the corresponding MRR,SR,EWR are measured by machining Titanium(Grade 5 & 2) by brass and brass coated electrode wire.In the third set of experiments,the fixed input variables are T_{on} =115;T_{off} = 55;IP = 150 are set and the corresponding MRR,SR,EWR are measured by machining Titanium(Grade 5 & 2) by brass and brass coated electrode wire.In the Fouth set of experiments,the fixed input variables are T_{on} =120;T_{off} = 50;IP = 200 are set and the corresponding MRR,SR,EWR are measured by machining Titanium(Grade 5 & 2) by brass and brass coated electrode wire.

7.EXPERIMENTAL RESULTS

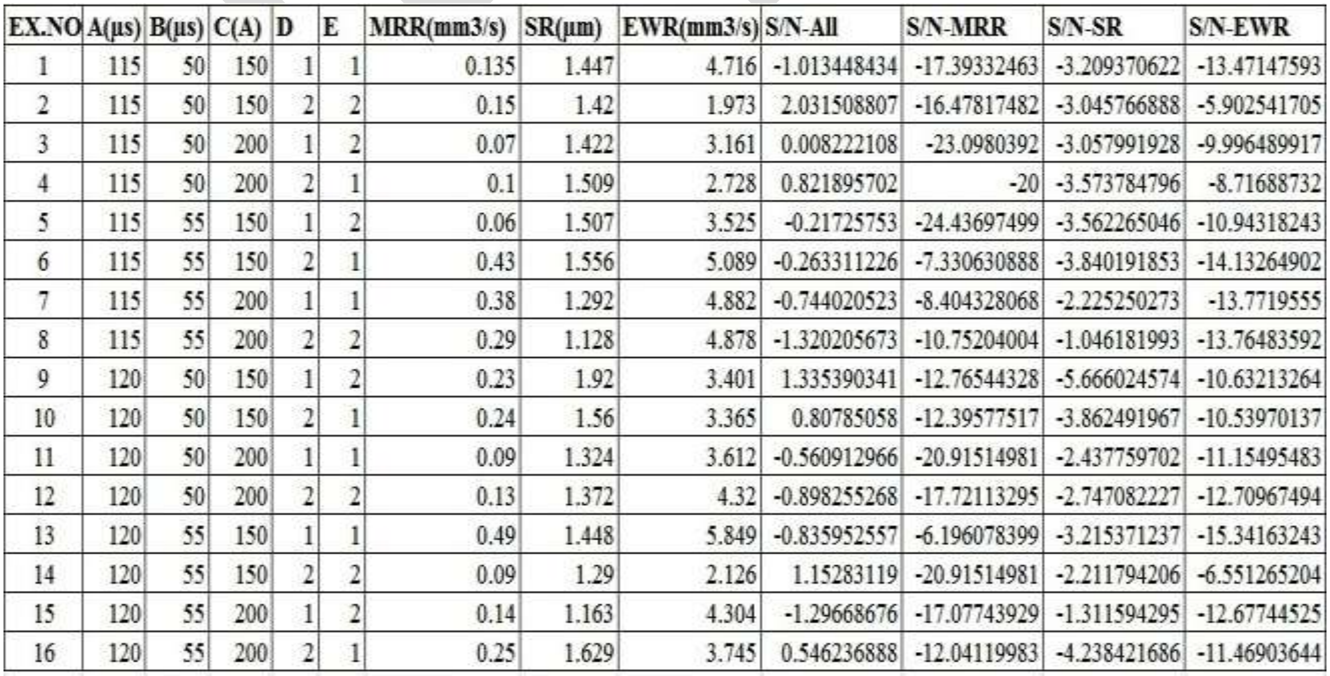
7.1 Design matrix and Observation table



EX.NO	A(µs)	B(µs)	C(A)	D	E	MRR(mm3/s)	SR(µm)	EWR(mm3/s)
1	115	50	150	1	1	0.135	1.447	4.716
2	115	50	150	2	2	0.15	1.42	1.973
3	115	50	200	1	2	0.07	1.422	3.161
4	115	50	200	2	1	0.1	1.509	2.728
5	115	55	150	1	2	0.06	1.507	3.525
6	115	55	150	2	1	0.43	1.556	5.089
7	115	55	200	1	1	0.38	1.292	4.882
8	115	55	200	2	2	0.29	1.128	4.878
9	120	50	150	1	2	0.23	1.92	3.401
10	120	50	150	2	1	0.24	1.56	3.365
11	120	50	200	1	1	0.09	1.324	3.612
12	120	50	200	2	2	0.13	1.372	4.32
13	120	55	150	1	1	0.49	1.448	5.849
14	120	55	150	2	2	0.09	1.29	2.126
15	120	55	200	1	2	0.14	1.163	4.304
16	120	55	200	2	1	0.25	1.629	3.745

Table 7.1 Design matrix and Observation table

7.2 Design matrix and Observation table by S/N Ratio



EX.NO	A(µs)	B(µs)	C(A)	D	E	MRR(mm3/s)	SR(µm)	EWR(mm3/s)	S/N-All	S/N-MRR	S/N-SR	S/N-EWR
1	115	50	150	1	1	0.135	1.447	4.716	-1.013448434	-17.39332463	-3.209370622	-13.47147593
2	115	50	150	2	2	0.15	1.42	1.973	2.031508807	-16.47817482	-3.045766888	-5.902541705
3	115	50	200	1	2	0.07	1.422	3.161	0.008222108	-23.0980392	-3.057991928	-9.996489917
4	115	50	200	2	1	0.1	1.509	2.728	0.821895702	-20	-3.573784796	-8.71688732
5	115	55	150	1	2	0.06	1.507	3.525	-0.21725753	-24.43697499	-3.562265046	-10.94318243
6	115	55	150	2	1	0.43	1.556	5.089	-0.263311226	-7.330630888	-3.840191853	-14.13264902
7	115	55	200	1	1	0.38	1.292	4.882	-0.744020523	-8.404328068	-2.225250273	-13.7719555
8	115	55	200	2	2	0.29	1.128	4.878	-1.320205673	-10.75204004	-1.046181993	-13.76483592
9	120	50	150	1	2	0.23	1.92	3.401	1.335390341	-12.76544328	-5.666024574	-10.63213264
10	120	50	150	2	1	0.24	1.56	3.365	0.80785058	-12.39577517	-3.862491967	-10.53970137
11	120	50	200	1	1	0.09	1.324	3.612	-0.560912966	-20.91514981	-2.437759702	-11.15495483
12	120	50	200	2	2	0.13	1.372	4.32	-0.898255268	-17.72113295	-2.747082227	-12.70967494
13	120	55	150	1	1	0.49	1.448	5.849	-0.835952557	-6.196078399	-3.215371237	-15.34163243
14	120	55	150	2	2	0.09	1.29	2.126	1.15283119	-20.91514981	-2.211794206	-6.551265204
15	120	55	200	1	2	0.14	1.163	4.304	-1.29668676	-17.07743929	-1.311594295	-12.67744525
16	120	55	200	2	1	0.25	1.629	3.745	0.546236888	-12.04119983	-4.238421686	-11.46903644

Table 7.2 Design matrix and Observation table by S/N Ratio

7.3 Graphs based on S/N ratio

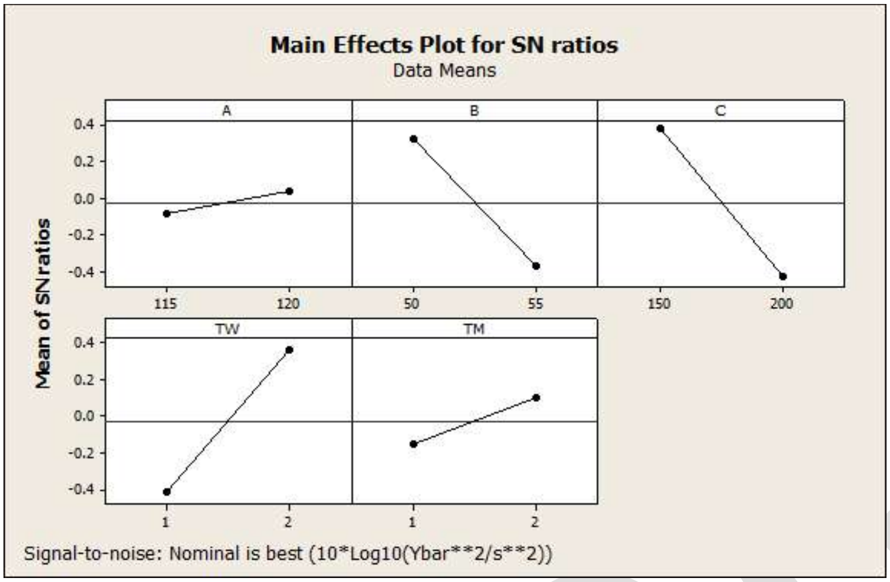


Fig :7.3 Optimal set of input parameters for nominal output response

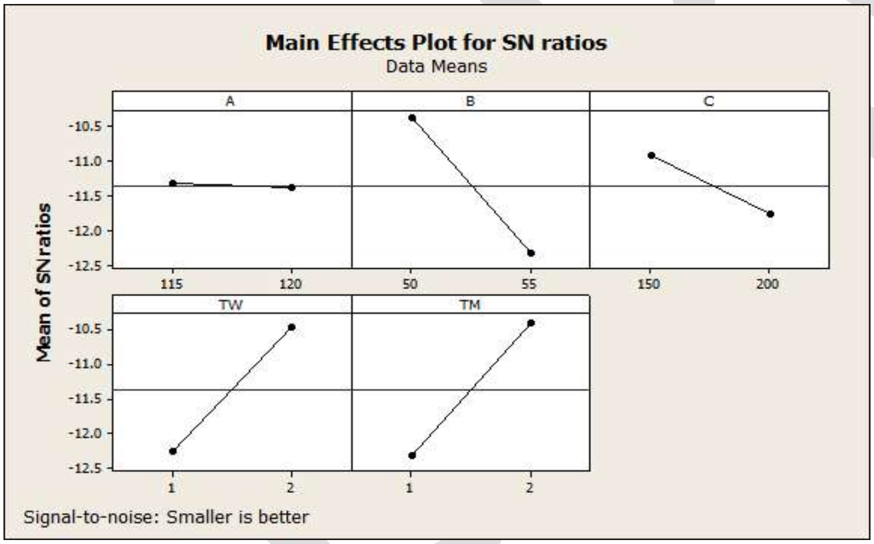


Fig :7.4 Optimal set of input parameters for minimum EWR

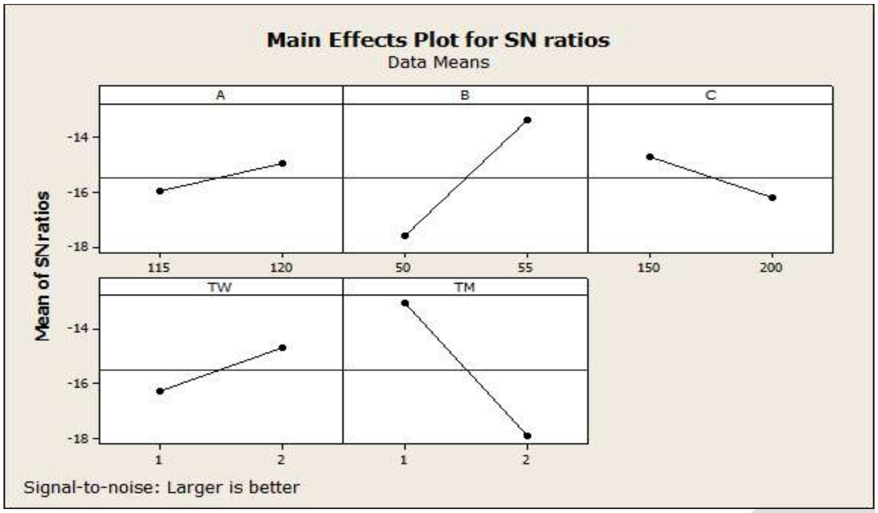


Fig :7.5 Optimal set of input parameters for maximum MRR

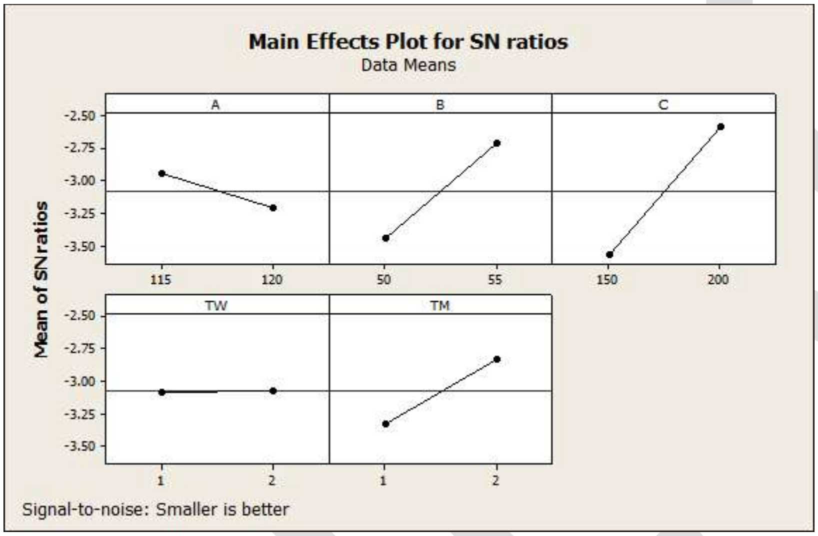


Fig 7.6 Optimal set of input parameters for minimum SR

8.INFERENCE

It is evident from the results that, MRR increases upon increasing Pulse on Time, Pulse off Time, Pulse Peak Current. By setting the input parameters as A2,B1,C1,D2,E2 , we can achieve the nominal output response (ie Max MRR, Min SR and EWR).And by selecting A2,B2,C2,D1,E1, as input parameters, we can achieve maximum Metal Removal Rate(MRR).Surface Roughness decreases upon increasing Pulse on Time and increasing upon increasing Pulse off time and Peak Current. By framing on A2,B1,C1,D1,E1 as input parameters, we can achieve minimal Surface Roughness(SR).EWR reduces upon increasing Pulse off Time and Peak Current. By choosing the input parameters A2,B2,C2,D1,E1 as, we can achieve minimal Electrode Wear Rate(EWR).

9.CONFIRMATION EXPERIMENT:

The confirmation experiment is the final step in any design of experiment process. Table 9.1, Table 9.2 and Table9.3 showsthe comparison of the predicted value with the new experimental value for the selected combinations of the machining parameters. As shown in the tables, the experimental values agree reasonably well with predictions because an error of 2.65 % for the S/N ratio of MRR and 9.12 % for the S/N ratio of surface roughness and 4.18% for an Electrode wear rate is observed when predicted results are compared with experimental values. Hence, the experimental result confirms the optimization of the machining parameters using orthogonal array method using S/N Ratio for enhancing the machining performance. However, the error in MRR,surface roughness and Electrode Wear rate can be further expected to reduce if the number of measurements is increased.

9.1 Result of confirmation experiment for MRR

	Predicted Value	Experimental Value	% error
Optimal Level	A2,B2,C2,D1,E1	A2,B2,C2,D1,E1	
MRR(mm^2/min)	63.12	60.54	
S/N Ratio for MRR	35.5589	34.6524	2.65

Table 9.1 Result of confirmation experiment for MRR

9.2 Result of confirmation experiment for SR

	Predicted Value	Experimental Value	% error
Optimal Level	A2,B1,C1,D1,E1	A2,B1,C1,D1,E1	
SR(μm)	1.29855	1.38	
S/N Ratio for SR	-3.37546	-3.04576	9.12

Table 9.2 Result of confirmation experiment for SR

9.3 Result of confirmation experiment for EWR

	Predicted Value	Experimental Value	% error
Optimal Level	A2,B2,C2,D1,E1	A2,B2,C2,D1,E1	
EWR(mm^3/s)	2.304	2.016	
S/N Ratio for EWR	-6.5287	-4.0797	4.18

Table 9.3 Result of confirmation experiment for EWR

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