International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.4, Jul - Aug. 2013 pp-1999-2006 ISSN: 2249-6645

Parametric Optimization of Electrochemical Machining Using Signal-To-Noise (S/N) Ratio

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Abstract: *Mild steel and aluminium are used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate and surface roughness. There are four machining parameters i.e. Voltage, Electrolyte flow rate, Tool feed rate and Current. Taguchi orthogonal array is designed with three levels of machining parameters with the help of software Minitab 15. Nine experiments are performed and material removal rate (MRR) and surface roughness is calculated. Metal removal rate and surface roughness are the most important output parameters, which decide the cutting performance. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better" and surface roughness was considered with the concept of "the smaller-the-better". The S/N ratio values are calculated by taking into consideration with the help of software Minitab 15. The MRR and surface roughness values measured from the experiments and their optimum value for maximum material removal rate and minimum surface roughness.*

Keywords: *Taguchi Method, Machining Parameters, Mild Steel, Aluminium alloy, signal to noise ratio.*

I. INTRODUCTION OF ECM

Electrochemical machining (ECM) is a method of removing metal by an electrochemical process. It is normally used for mass production and is used for working extremely hard materials or materials that are difficult to machine using conventional methods. In the ECM process, a cathode (tool) is advanced into an anode (work piece). The pressurized electrolyte is injected at a set temperature to the area being cut. The feed rate is the same as the rate of "liquefication" of the material. Electrochemical machining is one of the widely used non-traditional machining processes to machine complicated shapes for electrically conducting but difficult-to-machine materials such as super alloys, Ti-alloys, alloy steel, tool steel, stainless steel, etc. Use of optimal ECM process parameters can significantly reduce the ECM operating, tooling, and maintenance cost and will produce components of higher accuracy. Its use is limited to electrically conductive materials. Both external and internal geometries can be machined. High metal removal rates are possible with ECM, with no thermal or mechanical stresses being transferred to the part, and mirror surface finishes can be achieved. At high concentration of electrolyte, electrolytes do not behave ideally and resistance of the solution increases which may cause deviation from Faraday’s law and Ohm’s law. Further, it has been assumed that the process of ECM to be ideal in nature till it obeys Ohm’s law and Faraday’s law. But there have been no report on the applicability of these laws for electrochemical machining. In the ECM process, a cathode (tool) is advanced into an anode (work piece). The pressurized electrolyte is injected at a set temperature to the area being cut. As electrons across the gap, material from the work piece is dissolved, as the tool forms the desired shape of the work piece. The electrolytic fluid carries away the metal hydroxide formed in the process. In this process, a low voltage (5-15V) is applied across two electrodes with a small gap size (0.2 mm – 0.5 mm) and with a current of (20 – 100A). The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Signal to noise ratio and orthogonal array are two major tools used in robust design.

Electrochemical machining is one of the widely used non-traditional machining processes to machine complicated shapes for electrically conducting but difficult-to-machine materials such as super alloys, Ti-alloys, alloy steel, tool steel, stainless steel, etc. Use of optimal ECM process parameters can significantly reduce the ECM operating, tooling, and maintenance cost and will produce components of higher accuracy. Its use is limited to electrically conductive materials. Both external and internal geometries can be machined. High metal removal rates are possible with ECM, with no thermal or mechanical stresses being transferred to the part, and mirror surface finishes can be achieved. Electrochemical Machining (ECM) is good for steel and super alloys and most often used when machining either shaped holes or cavities into electrically conductive materials. At high concentration of electrolyte, electrolytes do not behave ideally and resistance of the solution increases which may cause deviation from Faraday’s law and Ohm’s law. Further, it has been assumed that the process of ECM to be ideal in nature till it obeys Ohm’s law and Faraday’s law. But there have been no report on the applicability of these laws for electrochemical machining. In the ECM process, a cathode (tool) is advanced into an anode (work piece). The pressurized electrolyte is injected at a set temperature to the area being cut. As electrons across the gap, material from the work piece is dissolved, as the tool forms the desired shape of the work piece. The electrolytic fluid carries away the metal hydroxide formed in the process. In this process, a low voltage (5-15V) is applied across two electrodes with a small gap size (0.2 mm – 0.5 mm) and with a current of (20 – 100A).

The influence of each control factor can be more clearly presented with response graphs. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too. Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs. Mild steel and aluminium are most suitable for the manufacture of parts such as heavy-duty axles and shafts, gears, bolts and studs. The parameters were used in this experiments are voltage, electrolyte flow rate, tool feed rate and current.

II. METHODOLOGY

- ***Analysis of Variance (ANOVA)***

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows

NOTATION

Following Notation are used for calculation of ANOVA method
C.F. = Correction factor
T = Total of all result
n = Total no. of experiments
ST = Total sum of squares to total variation.
Xi = Value of results of each experiments (i = 1 to 27)
SY = Sum of the squares of due to parameter Y (Y = P, S, A, T)
NY1, NY2, NY3 = Repeating number of each level (1, 2, 3) of parameter Y
XY1, XY2, XY3 = Values of result of each level (1, 2, 3) of parameter Y
FY= Degree of freedom (D.O.F.) of parameter of Y
fT = Total degree of freedom (D.O.F.)
fe = Degree of freedom (D.O.F.) of error terms
VY = Variance of parameter Y
Se = Sum of square of error terms
Ve = Variance of error terms
FY = F-ratio of parameter of Y
SY’ = Pure sum of square
CY= Percentage of contribution of parameter Y
Ce = Percentage of contribution of error CF = T2/n
ST = Σi=1 to 27 Xi2 – CF
SY = (XY12/NY1 + XY22/NY2 + XY32/NY3) – CF
fY = (number of levels of parameter Y) – 1
fT = (total number of results)-1
fe = fT - ΣfY
VY = SY/fY
Se = ST - ΣSY
Ve = Se/fe
FY = VY/Ve
SY’ = SY – (Ve*fz)
CY = SY’/ST * 100%
Ce = (1- ΣPY)*100%

- ***Signal to Noise Ratio Calculation***

Quality Characteristics:

S/N characteristics formulated for three different categories are as follows:

Larger is best characteristic:

Data sequence for MRR (Material Removal Rate), which are higher-the-better performance characteristic are pre-processed as per Eq.1
S/N= -10 log ((1/n) ((1/y2))................................1

Nominal and Smaller are Best Characteristics:

Data sequences for SR, which are lower-the-better performance characteristic, are pre-processed as per Eq.2 &3
S/N= -10 log (y/s2y)....................................2
S/N= -10 log ((1/n) (Σ (y2))....................................3
Where y^ is average of observed data y, sy2 is variance of y, and n is number of observations.

III. EXPERIMENTAL SET UP AND WORK PROCEDURE

Material Mild Steel

Mild steel is a type of steel that contains only a small amount of carbon and other elements. It is softer and can be shaped more easily than higher carbon steels. It also bends a long way instead of breaking because it is ductile. It is used on nails and some types of wire; it can be used to make bottle openers, chairs, staplers, staples, railings and most common metal products. Its name comes from the fact it only has less carbon than steel. Mild steel is used in almost all forms of industrial applications and industrial manufacturing. It is a cheaper alternative to steel, but still better than iron.

Aluminium Alloy

Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Properties of mild steel

Mild steel has a maximum limit of 0.2% carbon. The proportions of manganese (1.65%), copper (0.6%) and silicon (0.6%) are approximately fixed, while the proportions of cobalt, chromium, niobium, molybdenum, titanium, nickel, tungsten, vanadium and zirconium are not. A higher amount of carbon makes steels different from low carbon mild-type steels. A greater amount of carbon makes steel stronger, harder and very slightly stiffer than low carbon steel. However, the strength and hardness come at the price of a decrease in the ductility of this alloy. Carbon atoms get trapped in the interstitial sites of the iron lattice and make it stronger. What is known as mildest grade of carbon steel or 'mild steel' is typically low carbon steel with a comparatively low amount of carbon (0.16% to 0.2%). It has ferromagnetic properties, which make it ideal for the manufacture of many products. The calculated average industry grade mild steel density is 7.85 gm/cm3. Its Young's modulus, which is a measure of its stiffness, is around 210,000 MPa. Mild steel is the cheapest and most versatile forms of steel and serves every application which requires a bulk amount of steel. The low amount of alloying elements also makes mild steel vulnerable to rust. Naturally, people prefer stainless steel over mild steel, when they want a rust free material. Mild steel is also used in construction as structural steel. It is also widely used in the car manufacturing industry.

Properties of aluminium alloy

Good toughness
Good surface finish
Excellent corrosion resistance to atmospheric conditions
Good corrosion resistance to sea water
Can be anodized
Good weldability and brazability
Good workability

Equipment

After the test, the samples were cleaned and final weight was measured using a digital analytical balance precisa. Three measurements for each sample were taken. The weight loss per unit time for each specimen is calculated and considered as Material Removal Rate (MRR). Similarly the surface roughness was measured using a digital surface roughness tester. This process involves number variables.

Material Removal Rate (MRR) Measurement From the initial and final weight of job MRR is calculated and the relation is given below:

MRR = (Initial Wt - Final Wt)/Time Taken MRR is calculated for both set of experiment. Considering one set correct S/N ratio is calculated from MINITAB 15 software.

IV. EXPERIMENTAL DESIGN

The experimental layout for the machining parameters using the L9 orthogonal array was used in this study. This array consists of four control parameters and three level, as shown in table In the Taguchi method, most all of the observed values are calculated based on ‘the higher the better’ and ‘the smaller the better’. Thus in this study, the observed values of MRR, and SR were set to maximum, and minimum respectively. Next experimental trial was performed with three simple replications at each set value. Next, the optimization of the observed values was determined by comparing the standard analysis and analysis of variance (ANOVA) and SN ratio which was based on the Taguchi method.

Table I: Design Scheme of Experiment of Parameters and Levels

Notation	**Process parameter**	**Level 1**	**Level 2**	**Level 3**
A	Voltage (V)	05	10	15
B	Electrolyte flow rate(L/min)	20	25	30
C	Tool feed rate (mm/min)	0.10	0.20	0.30
D	Current(A)	20	60	100

Table II: Observed Values of MRR and SR for Mild Steel

Trial No.	**Control Parameter (level)**				**Result /Observed value**	
	Voltage	Electrolyte Flow rate	Tool feed rate	Current	MRR (g/min.)	SR (µm)
1	05	20	0.1	20	0.135	0.257
2	05	25	0.2	60	0.268	0.285
3	05	30	0.3	100	0.573	0.431
4	10	20	0.2	100	0.321	0.397
5	10	25	0.3	20	0.409	0.401
6	10	30	0.1	60	0.287	0.376
7	15	20	0.3	60	0.337	0.312
8	15	25	0.1	100	0.286	0.213
9	15	30	0.2	20	0.319	0.413

Table III: Observed Values of MRR and SR for Aluminum Alloy

Parameter (Y)	**DOF (fY)**	**Sum of squares (SY)**	**Mean variance (VY)**	**F-ratio (FY)**	**Pure sum (SY)**	**Contribution (%) (CY)**
A	2	0.0112	0.0056	0.0056	0.0112	18.30
B	2	0.0263	0.0131	0.0131	0.0263	**42.97**
C	2	0.0020	0.0010	0.0010	0.0020	3.27
D	2	0.0217	0.0108	0.0108	0.0217	35.46
Error	0					
Total	8	0.0612	0.0305			100.00

Table IV: Analysis of Variance (ANOVA) and F-Test for Mild Steel

Trial No.	**Control Parameter (level)**				**Result /Observed value**	
	Voltage	Electrolyte Flow rate	Tool feed rate	Current	MRR (g/min)	Surface Roughness (µm)
1	05	20	0.1	20	0.356	0.216
2	05	25	0.2	60	0.463	0.213
3	05	30	0.3	100	0.563	0.312
4	10	20	0.2	100	0.433	0.364
5	10	25	0.3	20	0.376	0.381
6	10	30	0.1	60	0.389	0.282
7	15	20	0.3	60	0.407	0.227
8	15	25	0.1	100	0.368	0.231
9	15	30	0.2	20	0.312	0.254

Table V: Analysis of Variance (ANOVA) and F-Test for Aluminum Alloy

Parameter (Y)	**DOF (fY)**	**Sum of squares (SY)**	**Mean variance (VY)**	**F-ratio (FY)**	**Pure sum (SY)**	**Contribution (%) (CY)**
A	2	0.0744	0.0372	0.0372	0.0744	47.11
B	2	0.0011	0.0005	0.0005	0.0011	0.70
C	2	0.0046	0.0023	0.0023	0.0046	2.91
D	2	0.0778	0.0389	0.0389	0.0778	**49.28**
Error	0					
Total	8					100.00

For Mild Steel

Table VI: S/N Ratio for MRR (Larger Is Better)

Experiment No.	A Voltage(V)	B Electrolyte flow rate (L/min)	C Tool feed (mm/min)	D Current(A)	MRR(g/min)	S/N Ratio
1	1	1	1	1	0.135	-17.393
2	1	2	2	2	0.268	-11.437
3	1	3	3	3	0.573	-4.8369
4	2	1	2	3	0.321	-9.8699
5	2	2	3	1	0.409	-7.7655
6	2	3	1	2	0.287	-10.8424
7	3	1	3	2	0.337	-9.4474
8	3	2	1	3	0.286	-10.8727
9	3	3	2	1	0.319	-9.9242

Table VII: S/N Ratio for Surface Rough (Smaller Is Better)

Experiment No.	A Voltage(V)	B Electrolyte flow rate (L/min)	C Tool feed (mm/min)	D Current(A)	SRF(µm)	S/N Ratio
1	1	1	1	1	0.257	11.8013
2	1	2	2	2	0.285	10.9031
3	1	3	3	3	0.431	7.3105
4	2	1	2	3	0.397	8.0242
5	2	2	3	1	0.401	7.9371
6	2	3	1	2	0.376	8.4962
7	3	1	3	2	0.312	10.1169
8	3	2	1	3	0.213	13.4324
9	3	3	2	1	0.413	7.6810

Taguchi Analysis: MRR (g/min) versus A, B, C, D

Response Table for Signal to Noise Ratios,
Larger is better

Level	Voltage(A)	Electrolyte flow rate(B)	Tool feed rate(C)	Current(D)
1	-11.223	-12.237	-13.036	-11.694
2	-9.493	10.025	-10.410	-10.576
3	-10.081	-8.534	-7.350	-8.526
Delta	1.730	3.702	5.686	3.168
Rank	4	2	1	3

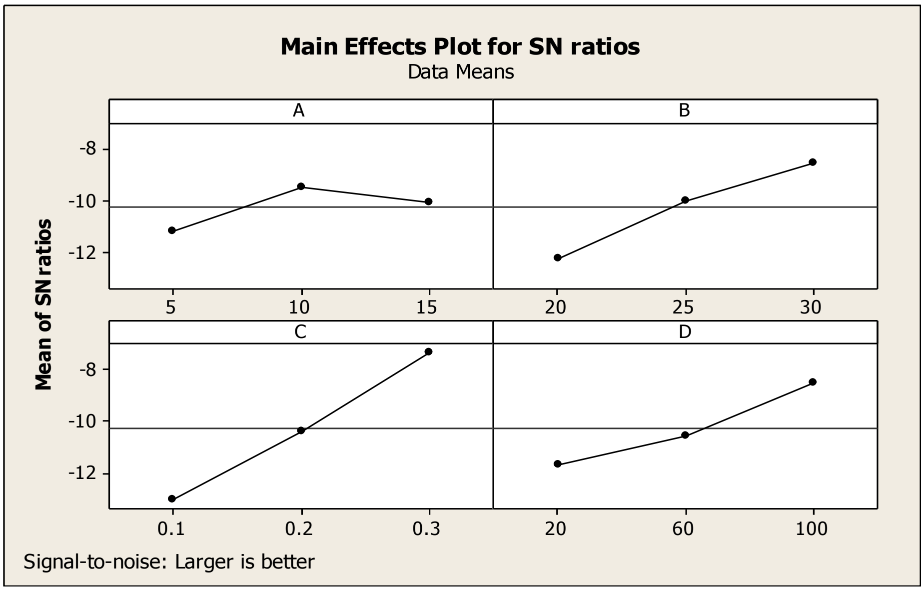

Figure 1: S/N Ratio of MRR for Different Levels

Taguchi Analysis: SR (μm) versus A, B, C, D
Response Table for Signal to Noise Ratios
Smaller is better

Level	Voltage(A)	Electrolyte flow rate(B)	Tool feed rate(C)	Current(D)
1	10.005	9.981	11.243	9.140
2	8.153	10.758	8.869	9.839
3	10.410	7.829	8.455	9.589
Delta	2.258	2.928	2.789	0.699
Rank	3	1	2	4

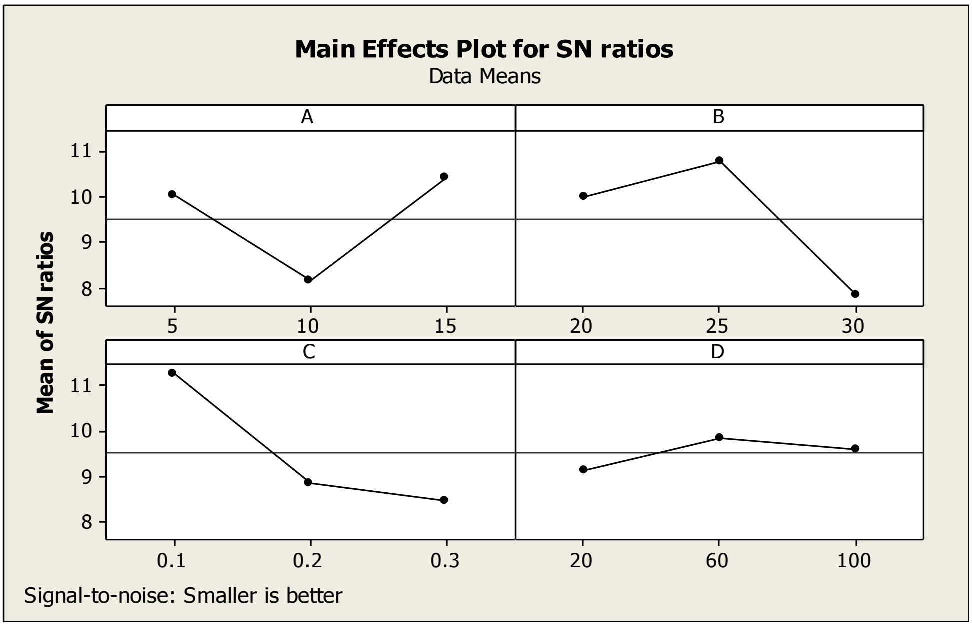

Figure 2: S/N Ratio of SR for Different Levels

For Aluminium Alloy

Table VIII: S/N Ratio for MRR (Larger Is Better)

Experiment No.	A Voltage(V)	B Electrolyte flow rate (L/min)	C Tool feed (mm/min)	D Current(A)	MRR(g/min)	S/N Ratio
1	1	1	1	1	0.356	-8.9710
2	1	2	2	2	0.463	-6.6884
3	1	3	3	3	0.563	-4.9898
4	2	1	2	3	0.433	-7.2702
5	2	2	3	1	0.376	-8.4962
6	2	3	1	2	0.389	-8.2010
7	3	1	3	2	0.407	-7.8081
8	3	2	1	3	0.368	-8.6830
9	3	3	2	1	0.312	-10.1169

Table IX: S/N Ratio for Surface Roughness (Smaller Is Better)

Experiment No.	A Voltage(V)	B Electrolyte flow rate (L/min)	C Tool feed (mm/min)	D Current(A)	SRF(μm)	S/N Ratio
1	1	1	1	1	0.216	13.3109
2	1	2	2	2	0.213	13.4324
3	1	3	3	3	0.312	10.1169
4	2	1	2	3	0.364	8.7780
5	2	2	3	1	0.381	8.3815
6	2	3	1	2	0.282	10.9950
7	3	1	3	2	0.227	12.8795
8	3	2	1	3	0.231	12.7278
9	3	3	2	1	0.254	11.9033

Taguchi Analysis: MRR (g/min) versus A, B, C, D

Response Table for Signal to Noise Ratios

Larger is better

Level	Voltage(A)	Electrolyte flow rate(B)	Tool feed rate(C)	Current(D)
1	-6.883	-8.016	-8.618	-9.195
2	-7.989	-7.956	-8.025	-7.566
3	-8.869	-7.769	-7.098	-6.981
Delta	1.986	0.247	1.520	2.214
Rank	2	4	3	1

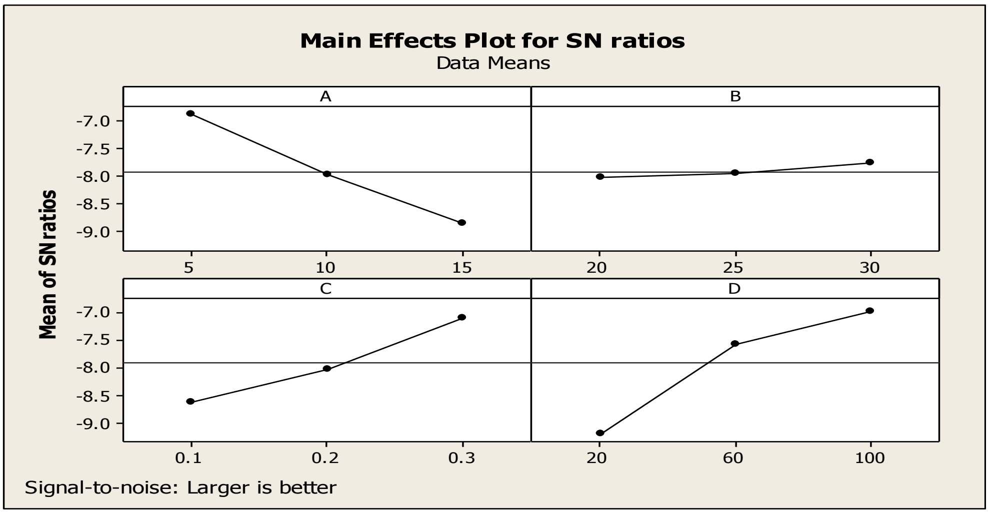

Figure 3: S/N Ratio of MRR for Different Levels

Taguchi Analysis: SR (□m) versus A, B, C, D

Response Table for Signal to Noise Ratios

Smaller is better

Level	Voltage(A)	Electrolyte flow rate(B)	Tool feed rate(C)	Current(D)
1	12.287	11.656	12.345	11.199
2	9.385	11.514	11.371	12.436
3	12.504	11.005	10.459	10.541
Delta	3.119	0.651	1.885	1.895
Rank	1	4	3	2

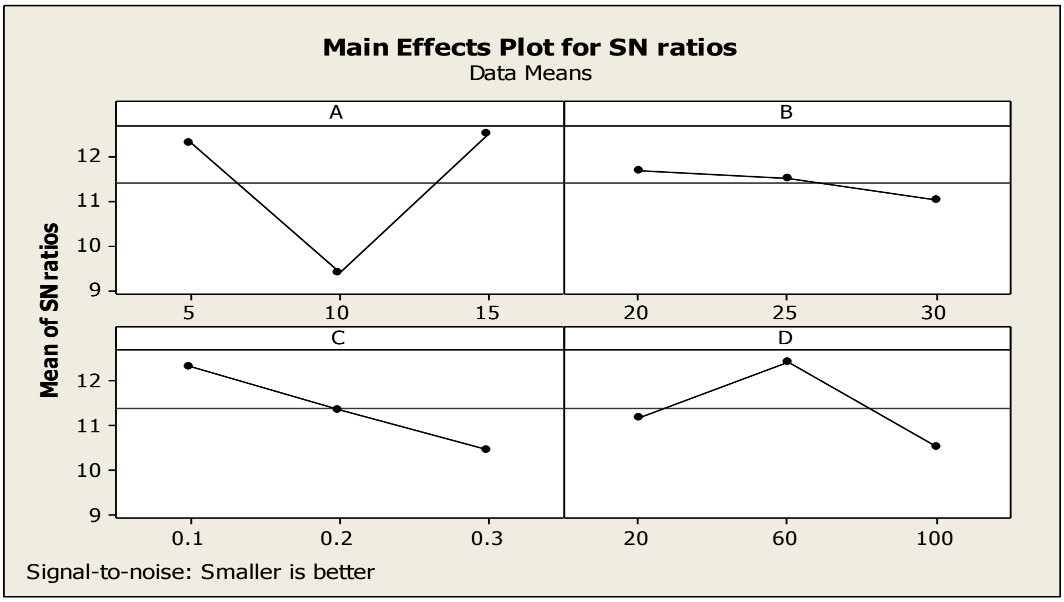

Figure 4: S/N Ratio of SR for Different Level

V. RESULT AND DISCUSSION

The following discussion focuses on the different of process parameters to the observed values (MRR and SR) based on the Taguchi methodology.

Material Removal Rate (MRR)

Main effects of MRR of each factor for various level conditions are shown in figure1. According to figure 1 the MRR increases with four major parameter A, B, C, and D. MRR is maximum in the case of **Voltage (A)** at level 2 (10), in the case of **Electrolyte flow rate (B)** at level 3 (30), in the case of **Tool feed rate (C)** MRR will be maximum at level 3 (0.3), and in the case of Current **(D)** at the level 3 (100). So the optimal parameter setting for the MRR found **A2B3C3D3**

Surface Roughness (SR)

Figure 2 evaluates the main effects of each factor for various level conditions. According to the figure 2 the surface Roughness decreases with four major parameter A, B, C, and D. SR will be minimum in the case of **Voltage (A)** at level 3 (15), in the case of **Electrolyte flow rate (B)** at level 2 (25), in the case of **Tool feed rate (C)** at level 1(0.1) and in the case of **Current (D)** condition surface Roughness will be minimum at level 2 (60). So the optimal parameter setting for minimum surface roughness is **A3B2C1D2.**

VI. CONCLUSIONS

This paper presents analysis of various parameters and on the basis of experimental results, analysis of variance (ANOVA), F-test and SN Ratio the following conclusions can be drawn for effective machining of mild steel and aluminium alloy by ECM process as follows:

- Electrolyte flow rate (B) is the most significant factor for mild steel machining in ECM. Meanwhile Voltage, Tool feed rate, and Current are sub significant in influencing. The recommended parametric combination for optimum material removal rate is **A2B3C3D3.**
- In case of Aluminium Alloy Current is most significant control factor and hence the optimum recommended parametric combination for optimum surface Roughness is **A3B2C1D2.**

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