International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Optimization Of Machining Process Parameters In Turning And Drilling By using Design Of Experiments With Aluminum 6061-O Alloy And Austenitic Stainless Steel

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Abstract*: *Optimization is required everywhere particularly in the industrial sector. As a part of that machining emphasized in this paper to optimize the parameters involved in the turning and drilling operation on CNC machines using the Aluminum and Stainless steel alloys. The task is initiated with design of experiments and hence the cost of operation is also reduced. During the experimental process the input parameters involved for turning were considered as cutting speed, feed and depth of cut. And for the drilling operation the input process parameters considered were speed of drill, feed. The output parameters emphasized were surface roughness and dimensional accuracy. By the investigation using the experiments, it in turn leads to an optimized environment for the operation that was carried out. Taguchi technique is a widely used and efficient technique for correlating the process parameters for an efficient and effective operation.

Then the process L9 and L16 orthogonal arrays were chosen and signal to noise ratios were computed. At the end the input parameters speed, feed, depth of cut, depth of drill and outcome parameters surface roughness, material removal rate and time of operation were optimized.

Keywords: Optimization, process parameters, design of experiments

I. INTRODUCTION

The work of turning and drilling is carried out on CNC machines and the work piece used was Aluminum 6061-O alloy and Aluminum 6061-O alloy. As the CNC machines possesses high level of accuracy and preciseness. The process parameters are to be quantified in the appropriate and adoptable manner in such a the machine should discharge its intended functions fatigue free and economical too. This is the base behind the work for the optimization of the parameters involved in the processes of turning as well as drilling. It gives an arena for the optimal process and also it shows how best a product can be made with minimum effort as perato's principle suggest that 'vital few, trivial many'.

Manuscript published on 30 September 2019.

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Here in the normal or conventional way of acquiring the products by assessing and ascertaining the outcomes in a priority manner.[1,2,3] It will further enhance the reduction of cost by accurate production of the products. Here in this work the CNC turning and drilling is done on the work pieces Aluminum 6061-O alloy and Aluminum 6061-O alloy.[17,18,19,20] The properties of the work piece materials are listed below in table 1 and table 2.

Table I: Aluminum 6061-O alloy properties

S No	Component	Wt (%)	S No	Component	Wt (%)
1	Al	95.8-98.6	6	Mg	0.8-1.2
2	Cr	0.04-0.35	7	Mn	Up to 0.15
3	Cu	0.15-0.4	8	Si	0.4-0.8
4	Fe	Up to 0.7	9	Tn	Up to 0.15
5	Zn	Up to 0.25	10	Other	Up to 0.25

Table II: Austenitic Stainless steel properties

S No	Component	Wt (%)	S No	Component	Wt (%)
1	C	0.08-0.12	6	Cr	16-20
2	Si	1.0	7	Mo	0.7-3
3	Mn	2.0-6.5	8	Ni	5-19
4	P	0.045-0.2	9	Cu	1-2.25
5	S	0.03-0.35			

The above mentioned two materials are of highly useful in aero space applications, there the accuracy of the materials are of high importance.[4,5,6,7] Based on this to optimize the productivity of the products production research is focused. The detailed methodology illustrated through the fig 1 flow chart below.

II. EXPERIMENT

The design of experiments and the actual way of conducting the experiments are subjected to the following assumptions. 1. The work pieces are of defect free both physically and chemically in composition. 2. The machine components does not undergo any wear within the limit of experiment. 3. The experiment does not have any interruptions what so ever because of power or any other mechanical reasons.
After through consideration of the parameters and all the other conditions and constraints the experiment is initiated theoretically for the formulation of the boundary conditions and then the actual experiment is carried out.

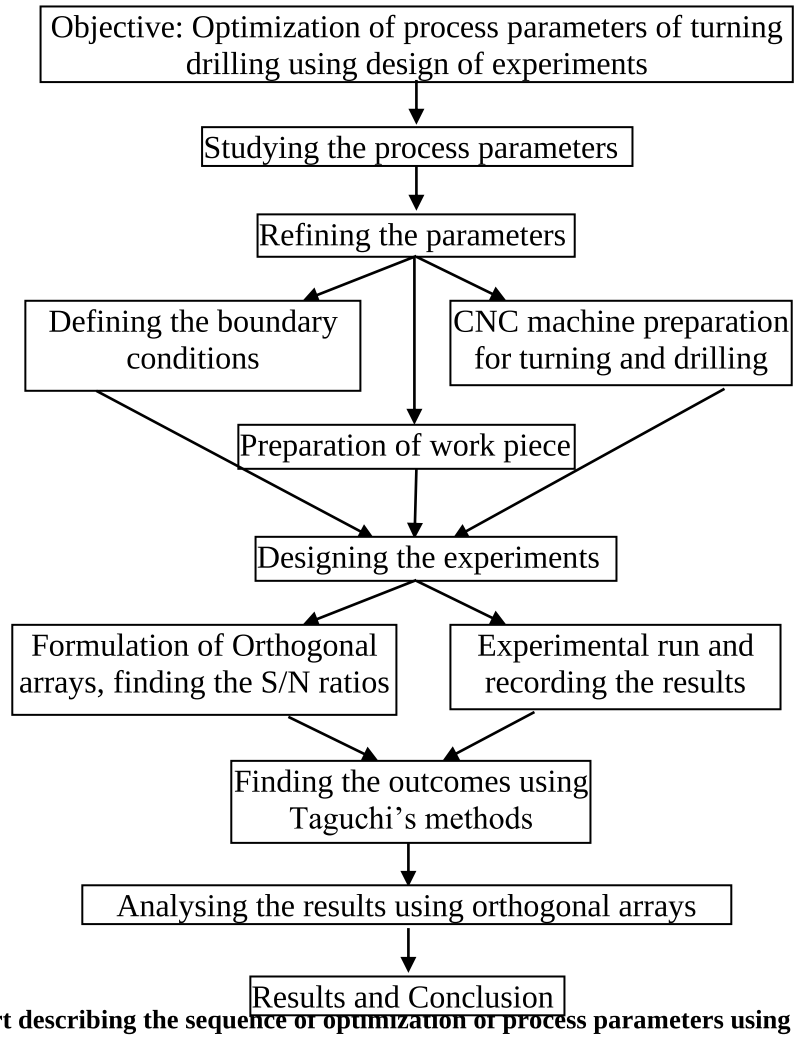


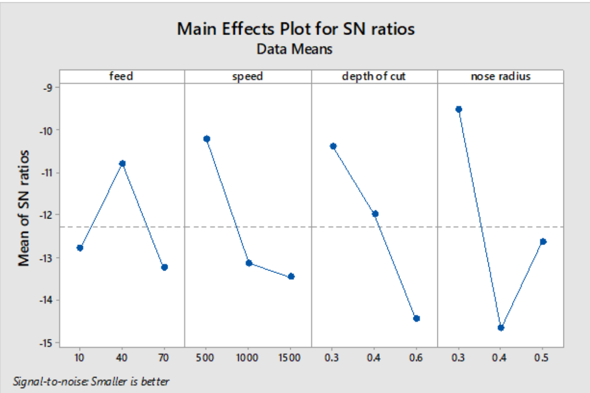
Figure 1: Flow chart describing the sequence of optimization of process parameters using design of experiments

The design of experiments (DOE) process have 3 main phases: they are 1. Planning phase, 2. Posting phase and 3. Analysis phase.[8,9,10] Besides to that the important step in the design of experiments process is to identify a combination of factors and followed by levels. Because these factors and levels gives the information for further processing. Out of many other techniques for design of experiments Taguchi's method is of more reliable and convenient too. Once the design of experiments is completed then the development of experiments has to be carried out with the Taguchi's method. It includes the orthogonal arrays (OA) formulations for the implementation of fractional factorial experiments; this will reduce the repetitions to the extent possible with accuracy.[11,12,13] There are two ways of observing and analyzing the factorial experiments one is observation of all at a time and the second is one factor to be observed at a time. And the first one is practically difficult when the experiment involves too many parameters and or factors. Hence the second way of observation is adopted. In this experiment each parameter has 5 levels and the degrees of freedom for each parameter are 4. Then the total calculated degrees of freedom is = 4^5 = 4 x 4 x 4 x 4 x 4 = 1024.

As the degrees of freedom was determined then the Orthogonal arrays must be defined as per taguchi's method within the condition of degrees of freedom should be less than or equal to orthogonal arrays. Hence with the conditions and constraints the best orthogonal array using the design of experiments of Taguchi is L9 and L16. The experiments were carried out on CNC turning and drilling machines.[14,15,16] The recorded values of the experiment were listed below in table 3.

Table III: Design of matrix for turning of Aluminum 6061-O alloy using L9 orthogonal array

Exp no.	Design of matrix				Feed rate (mm/min)	Cutting speed (rpm)	Depth of cut (mm)	Nose radius (mm)	Surface roughness (μm)	Material removal rate (mm^3/mm)	Machining time (min)	Machining force (N)	Power (W)
	A	B	C	D									
1	1	1	1	1	10	500	0.3	0.3	2.023	214.3	11.8	3.1	2..1
2	1	2	2	2	10	1000	0.4	0.4	6.141	254.7	10.9	2.7	3.4
3	1	3	3	3	10	1500	0.6	0.5	6.682	312.8	9.7	2.9	4.9
4	2	1	2	3	40	500	0.4	0.5	2.762	297.1	8.1	19.6	12.6
5	2	2	3	1	40	1000	0.6	0.3	3.579	596.8	6.4	14.8	18.3
6	2	3	1	2	40	1500	0.3	0.5	4.213	879.2	4.5	11.2	14.9
7	3	1	3	2	70	500	0.6	0.4	6.128	739.8	3.2	10.9	15.6
8	3	2	1	3	70	1000	0.3	0.5	4.257	928.4	2.1	11.8	16.7
9	3	3	2	1	70	1500	0.4	0.3	3.714	1021.1	0.9	16.2	24.8



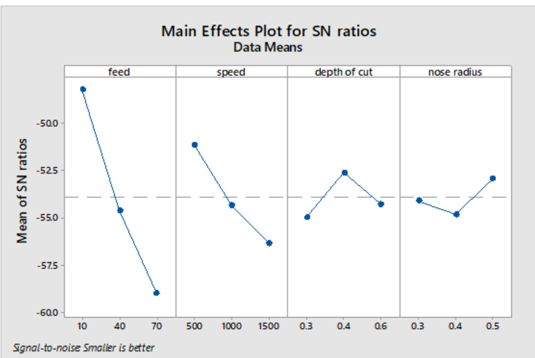
Response Table for Signal to Noise Ratios

Smaller is better

Level	feed	speed	depth of cut	nose radius
1	-12.794	-10.230	-10.398	-9.531
2	-10.797	-13.141	-11.995	-14.668
3	-13.242	-13.462	-14.440	-12.635
Delta	2.445	3.232	4.042	5.137
Rank	4	3	2	1

Fig 2 Main effects plot and SN ratio table for surface roughness

From the fig 2 the signal to noise ratio suggests that for the turning of the aluminum 6061-O alloy the best values for the input parameters or the working parameters values are as follows to obtain the minimum surface roughness. They are the feed should be used at 70 mm/min, speed of cut must be 1500rpm, depth of cut is at 0.6mm and nose radius will be 0.4mm. Under these conditions the minimum surface roughness can be obtained. And the in line comparison of the working parameters in terms of signal to noise ratio were given in table. The response table represents that nose radius gives have the highest effect on surface roughness followed by depth of cut then speed and at last the feed.



Response Table for Signal to Noise Ratios

Smaller is better

Level	feed	speed	depth of cut	nose radius
1	-48.22	-51.15	-54.95	-54.11
2	-54.62	-54.33	-52.59	-54.79
3	-58.97	-56.32	-54.27	-52.91
Delta	10.76	5.17	2.37	1.89
Rank	1	2	3	4

Fig 3 Main effects plot and SN ratio table for material removal rate

Retrieval Number: K16000981119/19©BEIESP
DOI: 10.35940/ijitee.K1600.0981119
Journal Website: www.ijitee.org

Published By:
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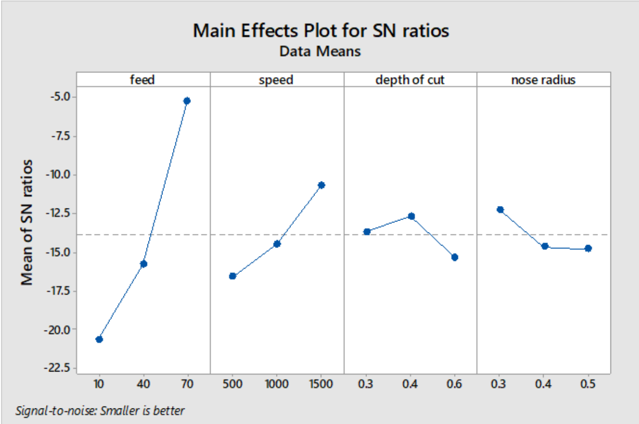
From the fig 3 the signal to noise ratio suggests that for the turning of the aluminum 6061-O alloy the best values for the input parameters or the working parameters values are as follows to obtain the optimal material removal rate. They are the feed should be used at 70 mm/min, speed of cut must be 1500rpm, depth of cut is at 0.3mm and nose radius will be 0.4mm. Under these conditions the minimum machining time can be obtained. And the in line comparison of the working parameters in terms of signal to noise ratio were given in table. The response table represents that feed gives have the highest effect on feed followed by speed then depth of cut then and at last the nose radius.



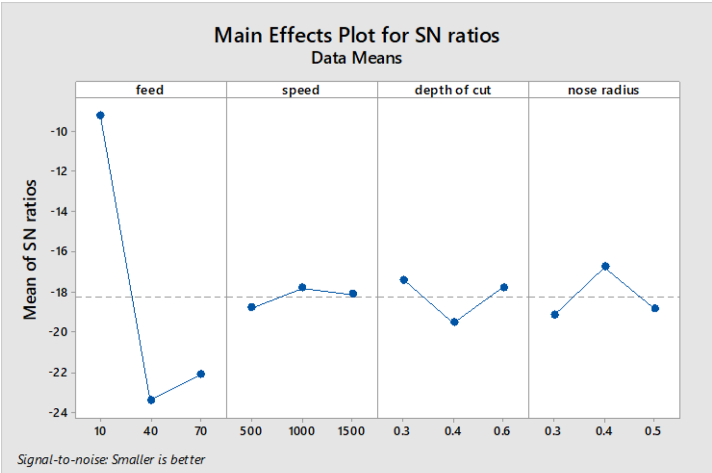
Response Table for Signal to Noise Ratios

Smaller is better

Level	feed	speed	depth of cut	nose radius
1	-20.641	-16.570	-13.649	-12.215
2	-15.786	-14.439	-12.668	-14.639
3	-5.211	-10.628	-15.321	-14.783
Delta	15.430	5.942	2.653	2.568
Rank	1	2	3	4

Fig 4 Main effects plot and SN ratio table for machining time

From the fig 4 the signal to noise ratio suggests that for the turning of the aluminum 6061-O alloy the best values for the input parameters or the working parameters values are as follows to obtain the minimum machining time. They are the feed should be used at 10 mm/min, speed of cut must be 500rpm, depth of cut is at 0.6mm and nose radius will be 0.5mm. Under these conditions the minimum machining time can be obtained. And the in line comparison of the working parameters in terms of signal to noise ratio were given in table. The response table represents that feed gives have the highest effect on surface roughness followed by speed then depth of cut then and at last the nose radius.



Response Table for Signal to Noise Ratios

Smaller is better

Level	feed	speed	depth of cut	nose radius
1	-9.234	-18.807	-17.416	-19.141
2	-23.412	-17.823	-19.554	-16.787
3	-22.125	-18.141	-17.801	-18.844
Delta	14.177	0.984	2.138	2.354
Rank	1	4	3	2

Fig 5 Main effects plot and SN ratio table for machining force

From the fig 5 the signal to noise ratio suggests that for the turning of the aluminum 6061-O alloy the best values for the input parameters or the working parameters values are as follows to obtain the minimum machining force. They are the feed should be used at 40 mm/min, speed of cut must be 500rpm, depth of cut is at 0.4mm and nose radius will be 0.3mm. Under these conditions the minimum machining time can be obtained. And the in line comparison of the working parameters in terms of signal to noise ratio were given in table. The response table represents that feed gives have the highest effect on surface roughness followed by nose radius then depth of cut then and at last the speed.

The below table IV shows the recorded values of the experiment of Aluminum 6061-O alloy using L16 orthogonal array.

Table IV: Design of matrix for turning of Aluminum 6061-O alloy using L16 orthogonal array

Exp no.	Design of matrix				Feed rate (mm/min)	Cutting speed (rpm)	Depth of cut (mm)	Nose radius (mm)	Surface roughness (µm)	Material removal rate (mm^3/mm)	Machining time (min)	Machining force (N)	Power (W)
	A	B	C	D									
1	1	1	1	1	10	500	0.4	0.3	2.198	232.4	12.9	2.6	2.3
2	1	1	1	2	10	500	0.4	0.8	3.457	279.1	12.1	2.9	2.8
3	1	1	2	1	10	500	0.7	0.3	4.023	294.3	11.8	3.3	3.1
4	1	1	2	2	10	500	0.7	0.8	7.141	314.7	10.9	2.8	3.5
5	1	2	1	1	10	1500	0.4	0.3	8.782	382.8	9.8	3.2	4.7
6	1	2	1	2	10	1500	0.4	0.8	3.862	397.1	8.3	18.7	12.3
7	1	2	2	1	10	1500	0.7	0.3	4.679	586.8	6.5	15.2	17.3
8	1	2	2	2	10	1500	0.7	0.8	5.713	876.2	4.9	11.5	15.7
9	2	1	1	1	70	500	0.4	0.3	8.198	769.8	3.9	11.7	16.4
10	2	1	1	2	70	500	0.4	0.8	5.457	938.4	3.6	21.2	17.1
11	2	1	2	1	70	500	0.7	0.3	7.684	1021.1	3.1	15.9	21.7
12	2	1	2	2	70	500	0.7	0.8	9.235	1129.2	2.7	16.2	22.8
13	2	2	1	1	70	1500	0.4	0.3	10.47	1044.5	2.3	17.1	23.1
14	2	2	1	2	70	1500	0.4	0.8	9.879	1182.7	1.8	17.6	23.4
15	2	2	2	1	70	1500	0.7	0.3	11.52	1287.2	1.2	18.2	24.1
16	2	2	2	2	70	1500	0.7	0.8	10.59	1293.5	0.8	18.9	24.7

The below table v shows the recorded values of the experiment of aluminum 6061-O alloy using L9 orthogonal array.

Table V: Design of matrix for drilling of Aluminum 6061-O alloy using L9 orthogonal array

Exp no.	Design of matrix				Feed rate (mm/min)	Cutting speed (rpm)	Depth of cut (mm)	Drill bit dia (mm)	Surface roughness (µm)	Material removal rate (mm^3/mm)	Machining time (min)	Machining force (N)	Power (W)
	A	B	C	D									
1	1	1	1	1	0.1	1000	5	4	2.31	214.3	11.8	2.8	2.6
2	1	2	2	2	0.1	1500	7	5	3.32	359.7	11.2	3.9	4.2
3	1	3	3	3	0.1	2000	8	6	3.98	404.8	10.4	5.1	7.6
4	2	1	2	3	0.2	1000	7	4	4.23	541.9	9.8	7.7	9.7
5	2	2	3	1	0.2	1500	8	5	4.98	684.6	8.1	10.2	11.3
6	2	3	1	2	0.2	2000	5	6	5.23	718.9	7.6	11.7	13.21
7	3	1	3	2	0.3	1000	8	4	6.43	847.8	5.5	12.6	15.7
8	3	2	1	3	0.3	1500	5	5	7.58	903.8	3.1	14.8	17.81
9	3	3	2	1	0.3	2000	7	6	8.61	1014.2	1.2	15.7	22.9

The below table 6 shows the recorded values of the experiment of Aluminum 6061-O alloy using L16 orthogonal array.

Table VI: Design of matrix for drilling of Austenitic stainless steel using L16 orthogonal array

Exp no.	Design of matrix				Feed rate (mm/min)	Cutting speed (rpm)	Depth of cut (mm)	Drill bit dia (mm)	Surface roughness (μm)	Material removal rate (mm^3/mm)	Machining time (min)	Machining force (N)	Power (W)
	A	B	C	D									
1	1	1	1	1	0.1	500	6	4	2.43	212.3	12.7	2.71	2.38
2	1	1	1	2	0.1	500	6	6	2.98	245.9	11.8	3.21	3.78
3	1	1	2	1	0.1	500	10	4	3.23	297.6	10.7	4.13	5.31
4	1	1	2	2	0.1	500	10	6	3.67	308.4	9.9	5.71	6.27
5	1	2	1	1	0.1	1000	6	4	4.21	334.6	9.1	6.54	7.92
6	1	2	1	2	0.1	1000	6	6	4.56	379.8	8.2	7.12	8.31
7	1	2	2	1	0.1	1000	10	4	5.21	421.5	8.8	7.93	10.8
8	1	2	2	2	0.1	1000	10	6	5.79	478.9	7.9	8.54	12.7
9	2	1	1	1	0.2	500	6	4	6.12	508.4	7.58	9.25	14.2
10	2	1	1	2	0.2	500	6	6	6.88	549.6	6.75	10.22	15.7
11	2	1	2	1	0.2	500	10	4	7.12	608.2	5.61	11.98	16.4
12	2	1	2	2	0.2	500	10	6	7.34	652.4	4.76	12.35	17.3
13	2	2	1	1	0.2	1000	6	4	7.59	757.9	3.85	14.37	18.9
14	2	2	1	2	0.2	1000	6	6	8.34	897.3	2.53	15.19	20.7
15	2	2	2	1	0.2	1000	10	4	8.84	956.2	1.77	16.23	21.6
16	2	2	2	2	0.2	1000	10	6	9.12	1032.7	0.91	17.6	23.1

RESULTS:

The below tables no 7,8 and 9 describes the outcomes of taguchi analysis of orthogonal arrays L16 array of Austenitic stainless steel with turning operation, L9 array of Aluminum 6061-O alloy with drilling operation and L16 array of Aluminum 6061-O alloy with drilling operation respectively.

Table VII L16 array of Austenitic stainless steel with turning operation

Sl no	parameter	Feed	Speed	Depth of cut	Nose radius	Response Table for Signal to Noise Ratios Smaller is better				
1	Surface roughness	70	1500	0.7	0.8	Level Delta Rank	Feed 5.77 (1)	Speed 3.04 (2)	Depth of cut 1.87 (3)	Nose radius 0.04 (4)
2	Material removal rate	70	1500	0.7	0.8	Level Delta Rank	Feed 8.91 (1)	Speed 3.77 (2)	Depth of cut 2.54 (3)	Nose radius 1.21 (4)
3	Machining time	10	500	0.4	0.3	Level Delta Rank	Feed 12.61 (1)	Speed 5.9 (2)	Depth of cut 3.37 (3)	Nose radius 1.58 (4)
4	Machining force	70	1500	0.7	0.8	Level Delta Rank	Feed 9.89 (1)	Speed 5.97 (2)	Depth of cut 1.57 (4)	Nose radius 2.29 (3)
5	Power	70	1500	0.7	0.8	Level Delta Rank	Feed 11.52 (1)	Speed 6.79 (2)	Depth of cut 2.97 (3)	Nose radius 1.42 (4)

Retrieval Number: K16000981119/19©BEIESP
DOI: 10.35940/ijitee.K1600.0981119
Journal Website: www.ijitee.org

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Table VIII L9 array of Aluminum 6061-O alloy with drilling operation

Sl no	parameter	Feed	Speed	Depth of cut	Nose radius	Response Table for Signal to Noise Ratios Smaller is better				
1	Surface roughness	0.3	2000	0.8	9	Level Delta Rank	Feed 7.58 (1)	Speed 3.03 (2)	Depth of cut 0.95 (3)	Nose radius 0.734 (4)
2	Material removal rate	0.3	2000	0.8	7.5	Level Delta Rank	Feed 9.31 (1)	Speed 3.18 (2)	Depth of cut 1.51 (3)	Nose radius 1.12 (4)
3	Machining time	0.1	1000	8	7.5	Level Delta Rank	Feed 12.18 (1)	Speed 5.5 (2)	Depth of cut 3.64 (4)	Nose radius 4.07 (3)
4	Machining force	0.3	2000	.8	9	Level Delta Rank	Feed 11.47 (1)	Speed 3.58 (2)	Depth of cut 0.95 (4)	Nose radius 0.75 (3)
5	Power	0.3	2000	8	9	Level Delta Rank	Feed 12.58 (1)	Speed 5.09 (2)	Depth of cut 2.29 (3)	Nose radius 1.94 (4)

Table IX L16 array of Austenitic stainless steel with drilling operation

Sl no	parameter	Feed	Speed	Depth of cut	Nose radius	Response Table for Signal to Noise Ratios Smaller is better				
1	Surface roughness	0.2	1000	10	12	Level Delta Rank	Feed 5.88 (1)	Speed 2.99 (2)	Depth of cut 1.52 (3)	Nose radius 0.86 (4)
2	Material removal rate	0.2	1000	10	12	Level Delta Rank	Feed 6.96 (1)	Speed 3.78 (2)	Depth of cut 1.90 (3)	Nose radius 0.90 (4)
3	Machining time	0.1	500	6	10	Level Delta Rank	Feed 8.96 (1)	Speed 6.06 (2)	Depth of cut 3.11 (3)	Nose radius 1.88 (4)
4	Machining force	0.2	1000	10	12	Level Delta Rank	Feed 7.82 (1)	Speed 4.59 (2)	Depth of cut 2.27 (3)	Nose radius 1.00 (4)
5	Power	0.2	1000	10	12	Level Delta Rank	Feed 9.15 (1)	Speed 4.92 (2)	Depth of cut 2.74 (3)	Nose radius 1.25 (4)

FUNDING: All the funds required for the experiment are arranged by our self only.
DATA AVAILABILITY: The data required for the research is collected from the text books, references cited below.
CONFLICTS OF INTREST: The authors do not have any conflicts of interest with research being carried out.

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