Detailed Study on Cutting Parameters Affecting the Performance of Vertical Milling Using Taguchi Method

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Abstract: Milling is the technique for removing the metal by feeding the work past a pivoting multipoint cutter. Milling machine is one among the principal fundamental machine tools in an instrument space as about every one of the tasks will be performed on that with high exactness. The objective of the current work is to use taguchi methodology to study the effect of milling parameters like cutting speed, depth of cut, feed rate, on the surface roughness, Material Removal rate (MRR) and chip thickness (Ct). The current work is carried out on vertical milling machine with types of specimens made up of carbon steel and aluminum respectively.

Keywords: Vertical milling, Taguchi methodology, Cutting parameters, Surface roughness.

1. INTRODUCTION

Milling is the technique for removing the metal by feeding the work past a pivoting multipoint cutter. In edge activity, the speed of metal removal is quick in light of the fact that the cutter pivots at a rapid and has a few cutting edges. In this way, the jobs square measure machined at quicker rate than with single reason apparatuses and accordingly the surface end is also higher due to multi cutting edges

Milling machine is one among the principal fundamental machine tools in an instrument space as about every one of the tasks will be performed on that with high exactness. Mill operator expands crafted by a shaping machine and may make the plain and bended surfaces and volute grooves and so on. The mill operator is likewise accordingly sorted out that the numerous cutters square measure mounted on the arbor at identical time, in this manner expanding the metal removal rate and allowing numerous surfaces to be machined at identical time. The activity of edge cutter is monstrously very surprising from that of a drill or shaper machine. In edge activity, the main edge of the cutter is whole interminably in contact with the material being cut. The cut grabs well-ordered completely.

Benardos [1] made a detailed review on predicting the surface roughness for milling operation and presented various methodologies to predict the surface roughness. Noordin et al. [2] used Response Surface Methodology (RSM) approach to study the performance of a multilayer tungsten carbide tools while turning AISI 1045 steel under dry conditions with constant depth of cut. The effect of feed, side cutting edge angle (SCEA), force and cutting speed are studied using face centered central composite design (FCCCD).

Vivancos et al. [3] introduced specialized model to propel machine parameters of a fast handling of solidified steels used for injection molds. A factorial arrangement was used to demonstrate the lead of the surface roughness as a component of speed, feed, and depth of cut. Oktem et al. [4] used a response surface methodology to choose the perfect cutting conditions for the surface roughness in handling mold surfaces. They merged the surface response technique with the hereditary calculation. Their half and half technique improved the surface roughness by 10%. Mohammad Hayajneh [5] et al. fabricated a relapse model for surface roughness to consider the effects of spindle speed, cutting feed rate, depth of cut and their two-way communications. The cutting parameters were picked as four degrees of cutting speed, seven degrees of feed rate and three degrees of depth of cut. Nalbant et al. [6] used a Taguchi technique to find the ideal cutting parameters for surface roughness in turning activities of AISI 1030 steel bars using TiN secured gadgets. Three cutting parameters, specifically, implant extend, feed rate, and depth of cut, are overhauled with thoughts of surface roughness, and so forth. P. Palanisamy et al [7] separated the perfect cutting parameters for instance cutting power, instrument life, and feed rate, depth of cut, cutting speed, surface roughness, cutting power and amplitude of vibrations during steady material removal rate in a Universal processing machine by Genetic Algorithm.

1.1 OBJECTIVE OF THE PRESENT WORK

The objective of the current work is to use taguchi methodology to study the effect of milling parameters like cutting speed, depth of cut, feed rate, on the surface roughness, Material Removal rate (MRR) and chip thickness (Ct). The current work is carried out on vertical milling machine with types of specimens made up of carbon steel and aluminum respectively.

1.2Methodology

LMW JV55 THREE AXIS MILLING MACHINE was used for conducting the experiments. A combination of Mild Steel and CARBON steel was used as the work material and HIGH-SPEED STEEL tool was used as the cutting tool. The experimentation for this work was based on Taguchi's design of experiments (DOE) and orthogonal array. Countless experiments must be completed when the number of the process parameters increments. To clear this undertaking task, the Taguchi technique utilizes a unique plan of orthogonal arrays to study the whole parameter space with few examinations as it were. In this work, three cutting parameters namely, cutting speed, depths of cut and feed rate were considered for experimentation. Accordingly, there are three input parameters and for each parameter three levels were assumed. For three factors, three level experiment, Taguchi had specified L_9 orthogonal array for experimentation (Table 1.1a-1.1b). The response obtained from the trials conducted as per L_9 array experimentation was recorded and further analyzed. Table 1.1a-1.1b the parameters and their levels considered for the experiments. Table 1.8-1.9 shows the actual cutting parameters used for each trial of experiment and the corresponding values of observed Ra, chip thickness (C_t), MRR are obtained. The design of experiment (DOE) is an effective approach to optimize the output in various manufacturing-related processes. The DOE has been implemented to select manufacturing parameters that could result in a better-quality product. In this study, the minimum surface roughness, Chip thickness (C_t) and higher material removal rate of Square work piece was investigated. The L_9 orthogonal array was selected for this study. The below procedure can be followed while conducting the experiment for materials.

- Conducting experimentation by application of orthogonal array for design of experiments and implementing Taguchi method for finding the effect of cutting parameters on surface roughness, material removal rate and chip thickness in machining of aluminum/carbon steel.
- Study the effects of surface roughness, Material removal rate on the Aluminum/carbon steel by considering speed, feed, and depth of cut by using L_9 orthogonal array.
- Analyze the effect of input parameters on Material Removal rate and surface Roughness and chip thickness by using ANOVA.
- To find the single optimum parameter set, for higher material removal rate and minimum surface roughness and chip thickness.

1.3 Levels of Input Parameters Table 1.1

(a). Aluminum

Factors	Unit	Levels		
		vel 1	vel 2	vel 3
Speed	Rpm	450	550	650
Feed	Mm/min	228	280	330
Depth of cut	Mm	0.15	0.3	0.45

(b).carbon steel

Factors	Unit	Levels		
		vel 1	vel 2	vel 3
Speed	Rpm	600	700	800
Feed	Mm/ min	305	356	406
Depth of cut	Mm	0.15	0.3	0.45

1.4 EXPERIMENTAL WORK:

1.4.1 Specimen preparation:

Aluminum and carbon steel work pieces each of 25*25*100 mm

TABLE1.2:

1.4.2 Chemical Composition and properties of Aluminum:

Chemical Composition of aluminum

S.NO	ELEMENT	PERCENTAGE
1	Zinc	6.0
2	Magnesium	3.0
3	Copper	2.0
4	Nickel	1.0
5	Chromium	0.3
6	Zirconium	0.2
7	Boron	0.01
8	Aluminum	Balance

(b)Mechanical properties of aluminum

S.NO	PHASE	VALUES
1	Elastic modulus	70-80 Gpa
2	Density	2.81 g/cc
3	Poisson's ratio	0.33
4	Hardness(HB500)	60
5	Tensile strength (T)/compressive strength (C)	220 (T)

1.4.3 Chemical Composition and properties of: CARBON Steel Table1.3

(a) Chemical Composition

S.NO	ELEMENT	PERCENTAGE
1	Carbon	0.45
2	Manganese	0.8
3	Phosphorous	0.04
4	Sulphur	0.05
5	Iron	Remaining

(b) Mechanical properties

S.NO	Phase	Values
1	Hardening Temperature	760-870 °c
2	Density	7801 kg/m^3
3	Max hardness	60-64 hrc
4	Thermal conductivity	43 w/m/^{0}c
5	Modulus of Elasticity	212GPa

1.4.4 Equipment:

Figure: **1.1:** 3-axis milling machine

TABLE 1.4 Specification of LMW JV 55 three axis Milling machine

Table dimension Length, Width	900 mm 430 mm
Max Spindle speed Max. motor rating	150 – 8000 rpm 7 KW
Max. Feed rates	10000 mm/min

Max. Tool length max. tool weight (in each pot)	250 mm 7 kg

1.4.5 Cutter used:

The cutter of high speed steel of diameter 16mm is employed during this experimental work and it's shown in Figure 1.2.

Table 1.5: Specifications of cutter

Type	End mill cutter
Material	High speed steel
Diameter	16mm
Flutes	04

1.4.6 MEASUREMENT OF SURFACE ROUGHNESS The surface roughness tester MITUTOYO SURFTEST SJ-310 as shown in Figure 3.4 is employed to measure the surface roughness of the machined work piece. The surface roughness tester and its specifications are shown in Figure 1.3 and also the Table 1.6 severally.

Figure 1.3: Mitutoyo Surf test sj-310

Table 1.6: Specification of surface roughness tester

MODEL	SJ 310
Range	0 – 360 µm
Stylus type	SJ 310
Least count	0.02 µm

The objective is to maximise the MRR subjected to desired surface roughness value and it depends on the input parameters.

This will be facilitated to the method planner for conducting experiments while not trial and error method. This can reduce the cost of the experiments.

Table 1.7: Orthogonal array with process parameters (a). Aluminum

Speed (rpm)	Feed (mm/min)	Doc (mm)
450	228	0.15
450	280	0.3
450	330	0.45
550	330	0.15
550	228	0.3
550	280	0.45
650	280	0.15
650	330	0.3
650	228	0.45

(b). Carbon steel

Speed (rpm)	Feed (mm/min)	Doc (mm)
600	305	0.15
600	356	0.3
600	406	0.45
700	406	0.15
700	305	0.3
700	356	0.45
800	356	0.15
800	406	0.3
800	305	0.45

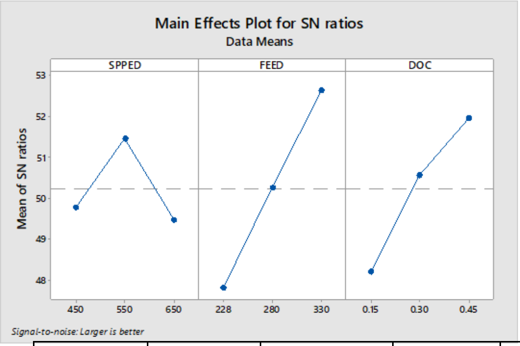
1.5 Experimental Observations in machining of Aluminum and carbon by HSS tool

Based on the orthogonal array L9 the parameters like surface roughness (Ra), Material removal rate (MRR), the chip thickness (Ct) is through an experiment evaluated and also the responses for Surface roughness (Ra), Material removal rate (MRR), and chip thickness (Ct) are shown within the Table 1.8& 1.9 below.

Table1.8 Experimental data and results for 3 parameters, corresponding MRR, surface roughness and chip thickness for HSS tool ALUMINUM

SPE ED, S(R PM)	FE ED (m m/ mi n)	DOC Cut, d(m m)	M RR m m^3/ mi n	SR(Ra) (µm)	C T (m m)
450	228	0.15	181	4.65	35
450	280	0.3	320	4.27	36
450	330	0.45	506	3.85	36
550	330	0.15	389	3.69	14
550	228	0.30	300	3.13	24
550	280	0.45	447	3.82	27
650	280	0.15	241	3.27	27
650	330	0.30	400	3.58	27
650	228	0.45	274	3.28	28

Table 1.9: Experimental data and results for 3 parameters, corresponding MRR, surface roughness and chip thickness for HSS tool CARBON STEEL



SPEED,S (RPM)	FEED (mm/min)	DOC Cut, d(mm)	MRR mm³/min	SR(Ra) (µm)	CT (mm)
600	305	0.15	163	0.61	31
600	356	0.3	164	0.82	34
600	406	0.45	180	1.09	37
700	406	0.15	371	1.26	36
700	305	0.30	136	0.63	33
700	356	0.45	350	0.93	38
800	356	0.15	177	0.47	34
800	406	0.30	221	1.08	25
800	305	0.45	138	0.48	31

1.6 RESULT AND DISCUSSIONS (i) ALUMINUM

(a) Analysis of Taguchi

The Response information for Material removal Rate (MRR)versus Speed (s), Feed (f), and Depth of cut (d) from the tables 1.10,1.11, the response plots for mean effects, S/N ratios, for aluminum. The response plots for mean effects, S/N ratios for mean square measure shown in Figures 1.4 to 1.5

Table 1.10: Response table for signal- to –noise ratio for Material removal rate over aluminum

Level	Speed (S)	Feed (f)	Depth of cut (d)
1	49.78	47.82	48.20
2	51.45	50.25	50.56
3	49.48	52.64	51.95
Delta(m ax-min)	1.97	4.82	3.75
Rank	3	1	2

Level	Speed(S)	Feed(f)	Depth of Cut(d)
1	1.4099	4.572	2.4847
2	0.8106	2.906	1.6793
3	4.0093	-1.248	2.0657
Delta(max -min)	3.1987	5.820	0.8055
Rank	2	1	3

Table 1.11: Response Table for MRR of aluminium

Figure 1.4: S/N ratio for material removal rate over aluminum

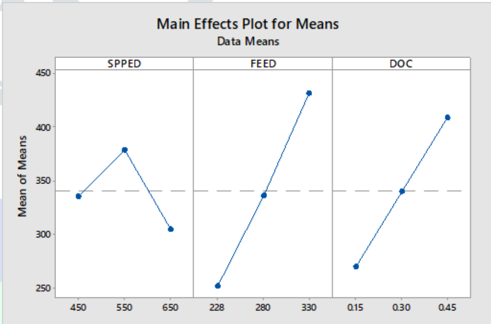


Figure 1.5: Plots of main effects for means for material removal rate over aluminum

The Response information for Surface Roughness (Ra) versus Speed (s), Feed (f), and Depth of cut (d) from the tables 1.12 and 1.13 the response plots for mean effects, S/N ratios for aluminum. The response plots for mean effects, S/N ratios for mean square measure shown in Figures 1.6 to 1.7

Table 1.12: Response table for signal- to –noise ratio for Surface Roughness (Ra) over aluminum

Level	Speed(S)	Feed(f)	DOC(d)
1	1.4099	4.5720	2.4847
2	0.8106	2.9065	1.6793
3	4.0093	-1.2487	2.0657
Delta(max -min)	3.1987	5.8207	0.8055
Rank	2	1	3

Table 1.13: Response Table for means for Surface Roughness (Ra) on Aluminum

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	335.7	251.7	270.3
2	378.7	336.0	340.0
3	305.6	431.7	409.0

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	0.8663	0.597	0.8187
2	0.9507	0.744	0.8453
3	0.6827	1.158	0.8357
elta(ma x-min)	0.2680	0.561	0.0267
Rank	2	1	3

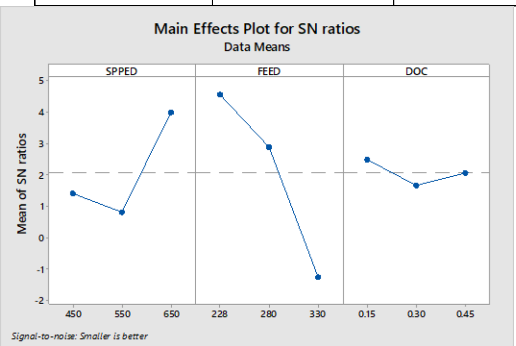


Figure 1.6: S/N ratio for surface roughness (R_a) over aluminium

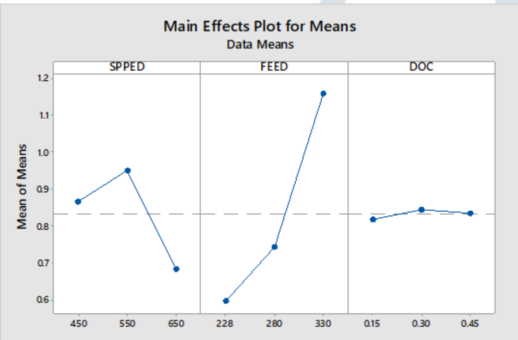


Figure 1.7: plots of main effects for means that for surface roughness (Ra) on aluminum

The Response information for Chip thickness (Ct) versus Speed (s), Feed (f), and Depth of cut (d) from the tables 1.14 and 1.15 the response plots for mean effects, S/N ratios for aluminum. The response plots for mean effects, S/N ratios for mean square measure shown in Figures 1.8 to 1.9.

Table1.14: Response table for signal-to-noise ratio chip thickness (C_t) on aluminum

Level	Speed(S)	Feed(f)	Depth of cut (d)
1	-31.04	-29.14	-27.48
2	-26.38	-29.46	-29.12
3	-28.73	-27.56	-29.57
Delta (max -min)	4.66	1.90	2.09
Rank	1	3	2

Table 1.15: Response table for means that for chip thickness (C_t) on aluminum

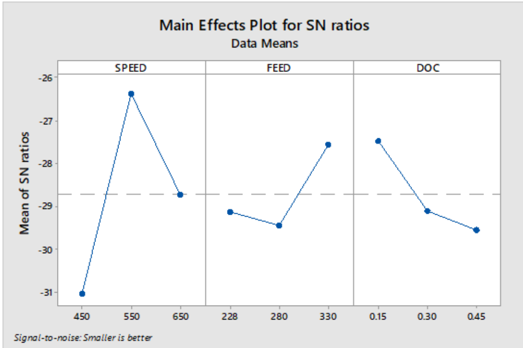


Figure 1.8: S/N ratio for Chip thickness (C_t) over Aluminum.

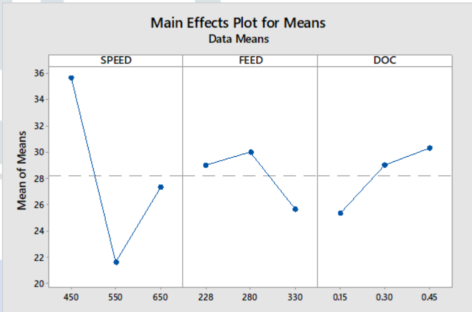


Figure1.9: plots of main effects for means that for chip thickness (Ct) over aluminum

(b) ANOVA for Machining of ALUMINUM by HSS tool

The results of ANOVA for the responses material removal rate (MRR), surface roughness (Ra) and chip thickness (C_t) are shown the following Tables (1.16-1.17-1.18) with Speed (s), Feed (f), and Depth of cut (d).

ANOVA for the Material removal Rate (MRR):

From Table 1.16 the % contribution of values for speed (10.66%), feed rate (55.03%) and depth of cut (34.01%). It is that the feed and speed have vast influence on material removal rate.

ANOVA for the response surface roughness (R_a):

From Table 1.17 the % contribution regarding values for speed (16.85%), feed rate (75.95%) and depth of cut (0.16%). It is executed as the speed and feed have vast

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	35.67	29.00	25.33
2	21.67	30.00	29.00
3	27.33	25.67	30.33

Delta (max -min)	14.00	4.33	5.00
Rank	1	3	2

influence on surface roughness (Ra).

ANOVA for the response chip thickness (C_t):

From Table 1.18 the % contribution regarding values for speed (97.59%), feed rate (0.59%) and depth of cut (1.77%). It is executed as the speed and feed have vast influence on chip thickness (C_t).

Table 1.16: ANOVA for the Material removal Rate (MRR) over Aluminum through HSS tool

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	% CONT RIBU TION
SPEED	2	0.089595	0.044798	35.52	0.027	10.66
FEED	2	0.462700	0.231350	183.46	0.005	55.03
DOC	2	0.26004	0.143002	113.40	0.009	34.01
ERROR	2	0.002522	0.001261			0.30
TOTAL	8					100.0

Table 1.17: ANOVA for the response surface roughness (Ra) over Aluminum through HSS tool

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	% CONT RIBU TION
SPEED	2	0.112670	0.056335	2.39	0.295	16.85
FEED	2	0.507904	0.253952	10.78	0.085	75.95
DOC	2	0.001094	0.000547	0.02	0.977	0.16
ERROR	2	0.047104	0.023552			7.04
TOTAL	8					100.0

Table 1.18: ANOVA for the response chip thickness (Ct) over Aluminum through HSS tool

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	% CONT RIBU TION
SPEED	2	757.060	378.530	1815.08	0.001	97.59
FEED	2	4.603	2.302	11.04	0.083	0.59
DOC	2	13.705	6.852	32.86	0.030	1.77
ERROR	2	0.417	0.209			0.05
TOTAL	8					100.0

(i) CARBON STEEL

(a) Analysis of Taguchi

The response information for **Material removal Rate (MRR)** with Speed (s), Feed (f), and Depth of cut (d) from the tables 1.19 and 1.20, the response plots because of mean effects, S/N ratios, for carbon steel. The response plots because of mean effects, S/N ratios because of mean are shown in Figures 1.10 to 1.11

Table 1.19: Response table for signal- to –noise ratio for MRR over Carbon steel

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	45.55	43.24	46.85
2	48.31	46.70	44.85
3	44.87	47.79	46.26
Delta(max -min)	3.76	4.56	2.28
Rank	2	1	3

Table 1.20: Response table for means that for Material removal rate on Carbon steel

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	169.0	145.7	236.7
2	285.7	230.0	173.7
3	178.3	257.3	222.7
Delta(max -min)	116.7	111.7	63.7
Rank	1	2	3

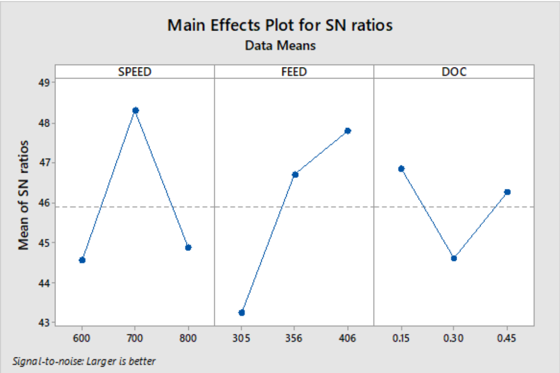


Figure 1.10: S/N ratio for MRR over Carbon steel

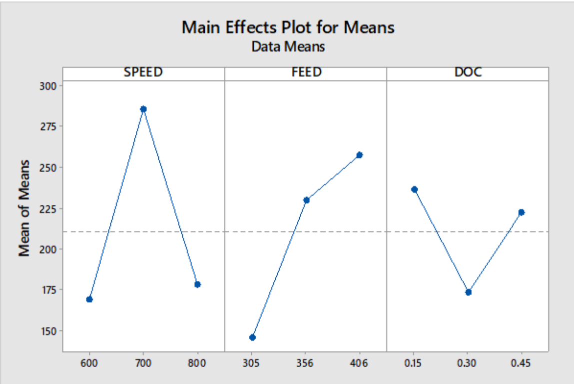


Figure 1.11: Plots of main effects for means that for MRR on carbon steel.

The Response information for Surface Roughness (Ra) with Speed (s), Feed (f), and Depth of cut (d) from the tables 1.21 and 1.22 the response plots because of mean effects, S/N ratios for Carbon steel. The response plots for mean effects, S/N ratios for mean are shown in Figures 1.12 to 1.13.

Table 1.21: Response table for signal- to –noise ratio for Surface Roughness (Ra) on Carbon steel

Level	Speed(S)	Feed(f)	Depth of cut (d)
1	-12.43	-11.39	-11.69
2	-11.13	-11.51	-11.37
3	-10.57	-11.24	-11.07
Delta(max -min)	1.86	0.27	0.62
Rank	1	3	2

Table 1.22: Response Table for means that for Surface Roughness (Ra) on carbon steel

Level	Speed(S)	Feed(f)	Depth of cut (d)
1	4.206	3.764	3.886
2	3.609	3.785	3.724
3	3.380	3.646	3.585
Delta(max -min)	0.827	0.139	0.301
Rank	1	3	2

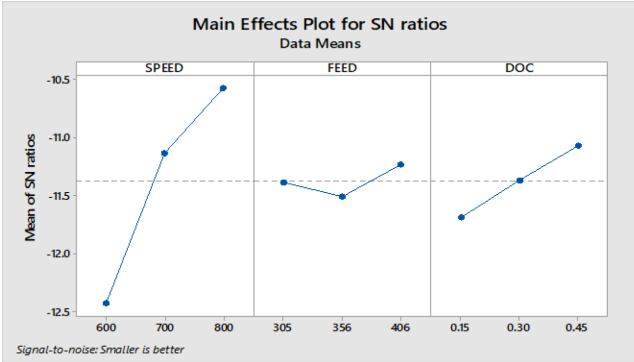


Figure 1.12: S/N ratio for surface roughness (Ra) on Carbon steel

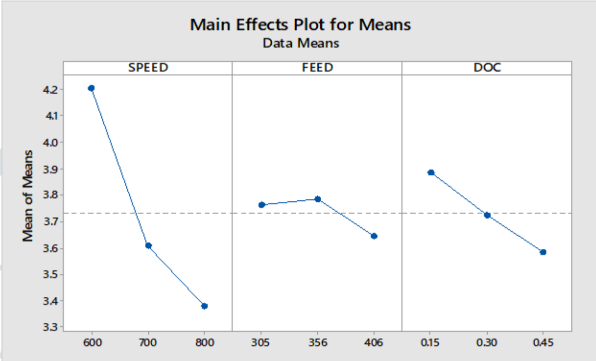


Figure 1.13: plots of main effects for means that for surface roughness (Ra) over Carbon steel.

The Response data for Chip thickness (Ct) versus Speed (s), Feed (f), and Depth of cut (d) from the tables 1.23 and 1.24 the response plots for mean effects, S/N ratios for Aluminum. The response plots for mean effects, S/N ratios for mean are shown in Figures 1.14 to 1.15.

Table 1.23: Response table for signal- to –noise ratio Chip thickness (Ct) on Carbon steel

Level	Speed(S)	Feed(f)	Depth of cut (d)
1	-30.61	-30.01	-30.53
2	-31.03	-30.95	-29.65
3	-29.47	-30.15	-30.93
Delta(max -min)	1.56	0.94	1.28
Rank	1	3	2

Table 1.24: Response Table for means that for Chip thickness (Ct) on Carbon steel

Level	Speed(S)	Feed(f)	Depth of cut(d)
1	34.00	31.67	33.67
2	35.67	35.67	30.67
3	30.00	3.67	35.33
Delta(max -min)	5.67	3	4.67
Rank	1	3	2

(b) ANOVA for Machining of CARBON STEEL by HSS tool

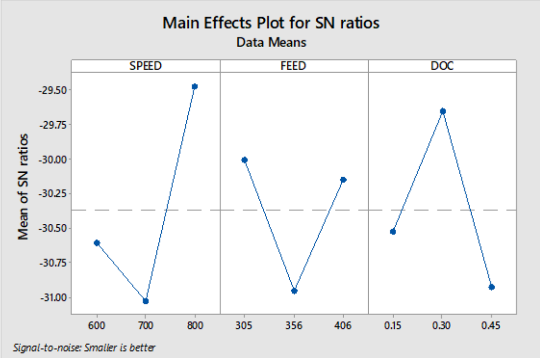


Figure 1.14: S/N ratio for Chip thickness (CT) on Carbon steel

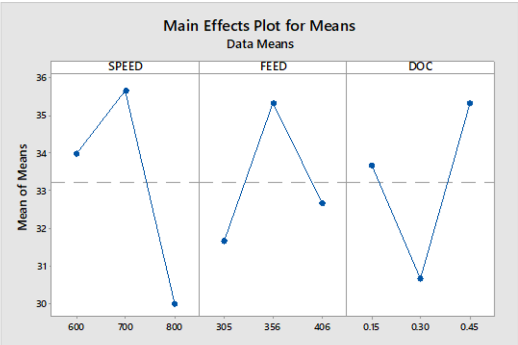


Figure 1.9: Plots of main effects for means that for Chip thickness (Ct) on Carbon steel

The results of ANOVA for the responses material removal rate (MRR), surface roughness (Ra) and chip thickness (Ct) are shown in the following Tables (1.25-1.26) versus Speed (s), Feed (f), and Depth of cut (d).

ANOVA for the Material removal Rate (MRR):

From Table 1.25the % contribution regarding for speed (12.65%), feed rate (59.24%) and depth of cut (8.82%). It is executed as depth of cut have vast influence on material removal rate.

ANOVA for the response surface roughness (R_a):

From Table 1.26 the % contribution regarding for speed (60.13 %), feed rate (1.62 %) and depth of cut (3.44%). It is executed as feed and depth of cut have vast influence on Surface Roughness (Ra).

ANOVA for the response chip thickness (C_t):

From Table 1.27 the % contribution regarding for speed (35.79%), feed rate (27.99%) and depth of cut (34.45%). It is executed as feed and depth of cut have vast influence on chip thickness (C_t).

Table 1.25: ANOVA for the Material removal Rate (MRR) over Carbon steel through HSS tool

SOURCE	DEREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	% CONT RIBU TION
SPEED	2	0.85079	0.42540	1.73	0.367	60.13
FEED	2	0.02295	0.01148	0.05	0.955	1.62
DOC	2	0.04861	0.02431	0.10	0.910	3.44
ERROR	2	0.49259	0.24630			34.81
TOTAL	8					100.00

Table 1.26: ANOVA for the response surface roughness (R_a) over Carbon Steel through HSS tool

SOURCE	DEREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	%CONT RIBUTI ON
SPEED	2	56.007	28.003	20.20	0.047	35.79
FEED	2	43.792	21.896	15.80	0.060	27.99
DOC	2	53.903	26.952	19.44	0.049	34.45
ERROR	2	2.772	2.772	1.386		1.77
TOTAL	8					100.00

Table 1.27: ANOVA for the response chip thickness (C_t) over Carbon Steel through HSS tool

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-RATIO	P-RATIO	% CONT RIBU TION
SPEED	2	0.000000	0.000000	0.66	0.604	12.65
FEED	2	0.000000	0.000000	3.07	0.246	59.24
DOC	2	0.000000	0.000000	0.46	0.686	8.82
ERROR	2	0.000000	0.000000			19.28
TOTAL	8					100.00

1.7 CONCLUSION:

Taguchi is an environment friendly and systematic methodology for optimizing milling parameters and can be utilized as an alternative than engineering judgment.

(ii) Aluminum:

- The optimum parameter setting speed 550 rpm, feed 330 mm/min and depth of cut 0.45 mm for obtaining maximum material removal rate (MRR).
- The optimum parameter setting speed 550 rpm, feed 330 mm/min and depth of cut 0.30 mm for obtaining minimum surface roughness (Ra)
- The optimum parameter setting speed 450 rpm, feed 228 mm/min and depth of cut 0.45 mm for obtaining minimum chip thickness (Ct).
- The ANOVA exhibits that the share contribution about feed (55.03%) is the dominant parameter followed with the aid of speed (10.66%) for Material Removal Rate.
- The ANOVA exhibits that the share contribution about speed (75.95%) is the dominant parameter followed with the aid of feed (16.85%) for Surface roughness (R_a).
- The ANOVA exhibits that the share contribution about speed (95.59%) is the dominant parameter followed with the aid of depth of cut (1.77%) for Chip thickness (C_t).

(ii) CARBON STEEL:

- The optimum parameter setting speed 700 rpm, feed 406 mm/min and depth of cut 0.15.mm for obtaining maximum material removal rate (MRR).
- The optimum parameter setting speed 600 rpm, feed 356 mm/min and depth of cut 0.15 mm for obtaining minimum surface roughness (Ra).
- The optimum parameter setting speed 700 rpm, feed 356 mm/min and depth of cut 0.45 mm for obtaining minimum Chip thickness (Ct).
- The ANOVA exhibits that the share contribution about feed (59.24 %) is the dominant parameter followed with the aid of speed (12.65%) for material removal rate (MRR).
- The ANOVA exhibits that the share contribution about depth of cut (3.44 %) is the dominant parameter followed with the aid of speed (60.13%) for surface roughness (R_a).
- The ANOVA exhibits that the share contribution about depth of cut (34.5 %) is the dominant parameter followed with the aid of speed (35.79%) for chip thickness (C_t)

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