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Optimization of Surface Roughness in CNC Turning of Aluminium 6061 Using Taguchi Techniques

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ABSTRACT:*The work and study presented in this paper aims to investigate the effect of the cutting speed, feed rate and depth of cut on surface roughness, in CNC turning of Aluminium (6061) in dry condition. The effect of cutting condition (cutting speed and feed rate) on surface roughness were studied and analysed. Design of experiments (DOE) were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness. The speed was identified as the most influential process parameter on surface roughness. The optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible.*
Keywords: *Surface Roughness, CNC Turning, Optimization, Taguchi Techniques, Aluminium*

I. INTRODUCTION

The drastic increase of consumer needs for quality metal cutting related products (more precise tolerance and better surface finish) has driven the metal cutting industry to continuously improve quality control of the metal cutting processes. The quality of surface roughness is an important requirement of many work pieces in machining operations. Within the metal cutting processes, the turning process is one of the most fundamental metal removal operations used in the manufacturing industry. Surface roughness, which is used to determine and evaluate the quality of a product, is one of the major quality attributes of a turned product. Surface roughness of a machined product could affect several of the product's functional attributes such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue. Therefore, surface roughness is one of the important quality aspects in turning operations. [12]

Hence, there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses by using experimental methods and statistical models. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. The aim of organization of this paper is to optimize the process parameters for minimum surface roughness in CNC turning process for Aluminium 6061.

II. LITERATURE REVIEW

Table 1 elucidates the work done by previous researchers.

Table 1: Summary of Research Papers

Ref. No.	Year	Author's Name	Material	Input Parameter	Output Parameter	Most Significant	
1.	2002	C. X. Feng, X. Wang	Steel 8620, Al 6061T	Work piece hardness (Steel (8620) HRB 86, AL (6061T) HRB 52), Feed (0.051, 0.203 mm/rev.), Tool point angle (35°, 80°), Depth of cut (0.51, 1.02 mm), Speed (1200, 1800 rpm), Cutting time	Surface Roughness	Workpiec e Hardness	Tool point angle
2.	2007	Hasan Gökkaya, MuammerNalbant	AISI 1030 Steel	Insert Radius (0.4, 0.8, 1.2 mm), DOC (0.5, 1, 1.5, 2, 2.5 mm), Feed (0.15, 0.2, 0.25, 0.30, 0.35 mm/rev.)	Surface Roughness	Feed	Insert Radius
3.	2012	H.K. Dave, L.S. Patel, H. K. Raval	EN-8, EN-31	Tool (CN1500, CC8020), Work Material (EN-8, EN-31), Cutting Speed (100, 150 m/min.), DOC (1, 1.5 mm), Feed (0.25, 0.30 mm/rev.)	Surface Roughness	Tool	DOC
					MRR	DOC	Tool
4.	2013	Harish Kumar Mohd. Abbas Dr.	MS 1010	Speed (1600, 1300, 1000 rpm), Feed (0.04, 0.03, 0.02 mm/rev.),	Surface Roughness	Speed	Feed

		AasMohmmad etc.		DOC (0.35, 0.30, 0.25 mm)			
5.	2011	IlhanAsilturk, HarunAkkus	AISI 4140 (51 HRC)	Cutting Speed (90, 120, 150 m/min.), Feed (0.18, 0.27, 0.36 mm/rev.), DOC (0.2, 0.4, 0.6 mm)	Surface Roughness	Feed	DOC
6.	2013	JakhalePrashant, Jadhav B. R.	High alloy steel	Cutting Speed (100, 125, 150 m/min.), Feed (0.24, 0.26, 0.28 mm/rev.), DOC (1, 2, 3 mm)	Surface Roughness	DOC	Speed
7.	2012	M. Kaladhar, K. Venkata, Ch. Srinivasa Rao	AISI 304 Austenitic Stainless Steel	Cutting Speed (150, 170, 190, 210 m/min.), Feed (0.15, 0.20, 0.25, 0.30 mm/rev.), DOC (0.5, 1.0, 1.5, 2.0 mm), Nose Radius (0.4, 0.8 mm)	Surface Roughness	Speed	Nose Radius
					MRR	DOC	Feed
8.	2011	M. Kaladhar, K. V. Subbaiah, Ch. Srinivasa, K. Narayana,	AISI 202 Austenitic Stainless Steel	Cutting Speed (111, 200 m/min.), Feed (0.15, 0.25 mm/rev.), DOC (0.25, 0.75 mm), Nose Radius (0.4, 0.8 mm)	Surface Roughness	Feed	Nose Radius
					MRR	DOC	Speed
9.	2012	M. Kaladhar, K. Venkata , Ch. Srinivasa Rao	AISI 304 Austenitic Stainless Steel	Cutting Speed (150, 170, 190, 210 m/min.), Feed (0.15, 0.20, 0.25, 0.30 mm/rev.), DOC (0.5, 1.0, 1.5, 2.0 mm), Nose Radius (0.4, 0.8 mm)	Surface Roughness	Feed	Nose Radius
10.	2010	M. Kaladhar, K. Venkata , Ch. Srinivasa Rao, K. Narayana Rao	AISI 202 Austenitic Stainless Steel 300 series 200 Series	Cutting Speed (111, 200 m/min.), Feed (0.15, 0.25 mm/rev.), DOC (0.25, 0.75 mm), Nose Radius (0.4, 0.8 mm)	Surface Roughness	Feed	Nose Radius
11.	2007	M. Nalbant, H. Gokkaya, G. Sur	AISI 1030 Steel	Nose Radius (0.4, 0.8, 1.2 mm), DOC (0.5, 1.5, 2.5 mm), Feed (0.15, 0.25, 0.35 mm/rev.)	Surface Roughness	Nose Radius	Feed
12.	2013	N.E. Edwin Paul, P. Marimuthu, R.Venkatesh	EN8 Steel	Cutting Speed (200, 240, 280 m/min.), Feed (0.15, 0.20, 0.25 mm/rev.), DOC (0.8, 1.0, 1.2 mm)	Surface Roughness	Speed	Feed
13.	2005	Özel T., Hsu T.K., Zeren E.	AISI H13 Steel	Cutting Edge Geometry (Honed, Chamfer), Workpiece Hardness (51.3, 54.7), Feed (0.05, 0.10, 0.20 mm/rev.), Cutting Speed (100, 200 m/min.)	Surface Roughness	Feed	Cutting Edge Geomet ry
14.	2014	Ranganath M. S., Vipin, R. S. Mishra	Aluminium (6061)	Speed (180, 450, 710 rpm), Feed (0.2, 0.315, 0.4 mm/rev.), DOC (0.2, 0.4, 0.6 mm)	Surface Roughness	Speed	DOC
					MRR	DOC	Speed
15.	2014	Ranganath M. S., Vipin, Nand Kumar, R. Srivastava	Aluminium KS1275	Depth of Cut (0.25, 0.50, 0.75 mm), Speed (1600, 1900, 2200 RPM), Feed (0.1, 0.2, 0.3 mm/rev.)	Surface Roughness	Feed	Depth of Cut
16.	2014	Ranganath M. S., Vipin	Aluminium (6061)	Tool Rake Angle (16, 18, 20°) Tool Nose Radius (0.4, 0.8, 1.2 mm), Cutting Speed (175, 225, 275 m/min.), Feed Rate (0.05, 0.1, 0.15 mm/rev.), Depth of Cut (0.1, 0.2, 0.3 mm)	Surface Roughness	Feed	Depth of Cut
17.	2014	Ranganath M. S., Vipin	Aluminium (6061)	Rake angle (16, 18, 20°) Nose Radius (0.4, 0.6, 0.8 mm)	Surface Roughness	Rake Angle	Nose Radius
18.	2012	Upinder Kumar Yadav, Deepak Narang, Pankaj Sharma	Medium Carbon steel AISI 1045	Cutting Speed (175, 220, 264 m/min.), Feed (0.1, 0.2, 0.3 mm/rev.), DOC (0.5, 1.0, 1.5 mm)	Surface Roughness	Feed	Speed
19.	2015	Ranganath M. S., Vipin Nand Kumar Rakesh Kumar	Aluminium KS 1275	Speed (1600, 1900, 2200rpm.), Feed (0.12, 0.18, 0.24 mm/rev.), DOC (0.25, 0.5, 0.75 mm)	Surface Roughness	Feed	Depth of Cut

III. EXPERIMENTAL WORK

Work piece material

Aluminium 6061 was selected as the work material. It is one of the most extensively used of the 6000 series aluminium alloys. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. It is widely used for producing automotive components by turning process.

It has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Alloy 6061 is easily welded and joined by various commercial methods. For screw machine applications, alloy 6061 has adequate machinability characteristics in the heat-treated condition. The different alloying elements present in this alloy are shown in the Table 2.

Table 2: Workpiece Composition

Components	% by weight
Aluminium (Al)	95.9 to 98.6 %
Magnesium (Mg)	0.8 to 1.2 %
Silicon (Si)	0.4 to 0.8 %
Iron (Fe)	0 to 0.7 %
Copper (Cu)	0.15 to 0.4 %
Chromium (Cr)	0.04 to 0.35 %
Zinc (Zn)	0 to 0.25 %
Manganese (Mn)	0 to 0.15 %
Residuals	0 to 0.15 %
Titanium (Ti)	0 to 0.15 %

Experimental plan

The experimental work was carried out on CNC turning center LMW LL20TL3 using CNMG insert of tool nose radius 0.8 mm. The specifications of the machine are given in Table 3.

Table 3: Machine Specification

Title	Description	Unit	LL20T L3
Capacity	Swing over bed	mm	510
	Chuck dia. max.	mm	200
	Max turning diameter	mm	320
	Max. turning length	mm	310
	Admit between centers	mm	420
Spindle	Spindle nose	type	A2 – 6
	Hole through spindle	mm	61
	Spindle speed	rpm	3500
	Spindle motor power(cont./15min)	kW	7.5/11
Feed system	Cross travel X-axis	mm	185
	Longitudinal travel Z-axis	mm	370
	Rapid traverse rate X/Z-axes	m/min	30 / 30
Turret	No. of stations	Nos.	8
	Tool shank size	mm	25×25
	Maximum boring bar dia.	mm	40
	Turret indexing	type	Hydraulic
Tailstock	Quill dia.	mm	75
	Quill stroke	mm	100
	Quill taper	-	MT-4
CNC system	Controller	-	Fanuc
Machine size	Front x Side	mm	2065 X 1925
	Machine weight (Approx.)	kg	3500

Fig. 1: CNC Turning- LMW LL20TL3 (Lakshmi Machine Works Limited)

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument. The Surtronic 3+ is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm. The parameter evaluation and other functions of the instrument are microprocessor based. The measurement results are displayed on LCD screen and can be output to an optional printer or computer for further results.

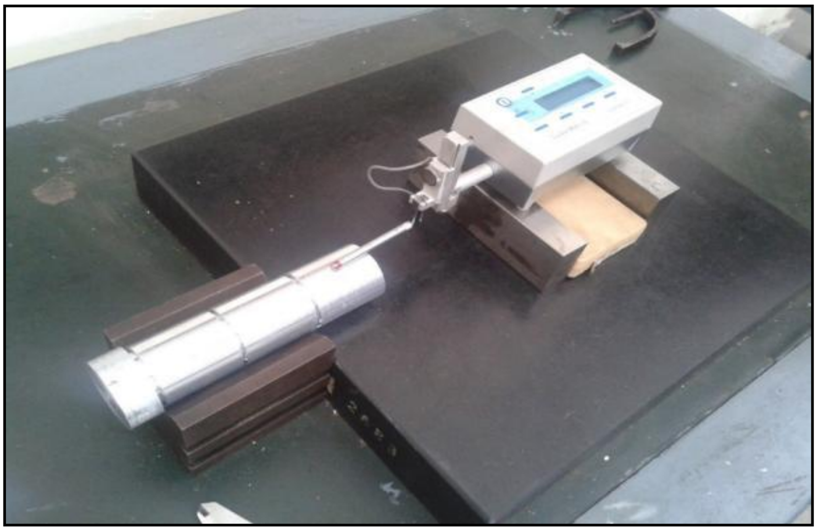

Fig. 2: Roughness Measuring Instrument(Taylor Hobson Surtronic 3+)

Design of Experiment

Taguchi's parametric design is the effective tool for robust design. It offers a simple and systematic qualitative optimal design to a relatively low cost. Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments (DOE). In this paper, Taguchi's (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed and depth of cut on Surface Roughness of Aluminium 6061 work material while turning it on a CNC turning centre to obtain an optimal setting of these parameters that may result in good surface finish.

As per Taguchi's method, the selected orthogonal array must be greater than or equal to the total degree of freedom required for the experiment. So, an L27 orthogonal array was selected for the present work. The non-linear relationship among the process parameters can be revealed when more than two levels of the parameters are considered. Hence each selected parameter was analyzed at three levels. The process parameters and their values at three levels are given in Table 4.

Table 4: Process parameters with their values at three levels			
Parameters	**Level 1**	**Level 2**	**Level 3**
Speed (RPM)	1600	1900	2200
Depth of Cut (mm)	0.25	0.50	0.75
Feed (mm/rev.)	0.12	0.18	0.24

Analysis

ANOVA was used for analyzing the results obtained. ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations. Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So in ANOVA, statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

IV. RESULTS AND DISCUSSION

The pieces of work material were set so as to conduct turning process three times on a single work piece while calculating the average roughness value, simultaneously by the stylus of the measuring instrument. To more closely replicate typical finish turning processes and to avoid excessive vibrations due to work place dimensional inaccuracies and defects, each work piece was rough-cut just prior to the measured finish cut. Thus simultaneously we could choose the machining zero required for generating cutting profile with reference to our work piece dimensions. On each piece, there were three different values of feed at one depth of cut and at a single speed. Surtronic 3+ instrument, used for surface roughness measurement, has a pick-up with a skid which is used to travel automatically through a drive motor. Thus such travel would at least require a distance of at least 8 mm. Thus we require appropriate surface travel distance on turned aluminum work piece. These dimensions were taken so as to keep travel the stylus on the best surface. The obtained results were analysed using Minitab software and all the values are shown in the Table 5.

Table 5: Input parameters and roughness observations					
S.No.	**Speed (RPM)**	**Doc (mm)**	**Feed (mm/rev.)**	**Ra (µm)**	**Rz (µm)**
1.	1600	0.25	0.12	0.559	4.350
2.	1600	0.25	0.18	1.516	6.996
3.	1600	0.25	0.24	1.890	8.310
4.	1600	0.50	0.12	0.684	4.336
5.	1600	0.50	0.18	0.957	5.603
6.	1600	0.50	0.24	1.755	9.786
7.	1600	0.75	0.12	0.671	4.786
8.	1600	0.75	0.18	1.137	9.810
9.	1600	0.75	0.24	3.080	12.900
10.	1900	0.25	0.12	0.533	3.420
11.	1900	0.25	0.18	0.773	4.820
12.	1900	0.25	0.24	2.523	12.000
13.	1900	0.50	0.12	0.688	4.393
14.	1900	0.50	0.18	1.090	8.110
15.	1900	0.50	0.24	2.383	1.560
16.	1900	0.75	0.12	0.782	4.310
17.	1900	0.75	0.18	1.493	7.383
18.	1900	0.75	0.24	1.646	7.916
19.	2200	0.25	0.12	0.554	3.183
20.	2200	0.25	0.18	1.448	7.493
21.	2200	0.25	0.24	2.176	9.083
22.	2200	0.50	0.12	0.657	4.346
23.	2200	0.50	0.18	1.793	8.183
24.	2200	0.50	0.24	2.316	1.370
25.	2200	0.75	0.12	0.721	5.120
26.	2200	0.75	0.18	1.445	6.920
27.	2200	0.75	0.24	1.836	9.500

The main effects plot for Means andSN Ratios are shown in Fig. 3 and Fig. 4 respectively.They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish.

It is evident from Fig. 3 that Ra is minimum at the second level of speed (*A*), first level of depth of cut (*B*) and first level of feed (*C*). In Fig. 4, the main effect plot for SN ratios of the Surface roughness is shown. Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

Fig. 3: Main Effects Plot for Means

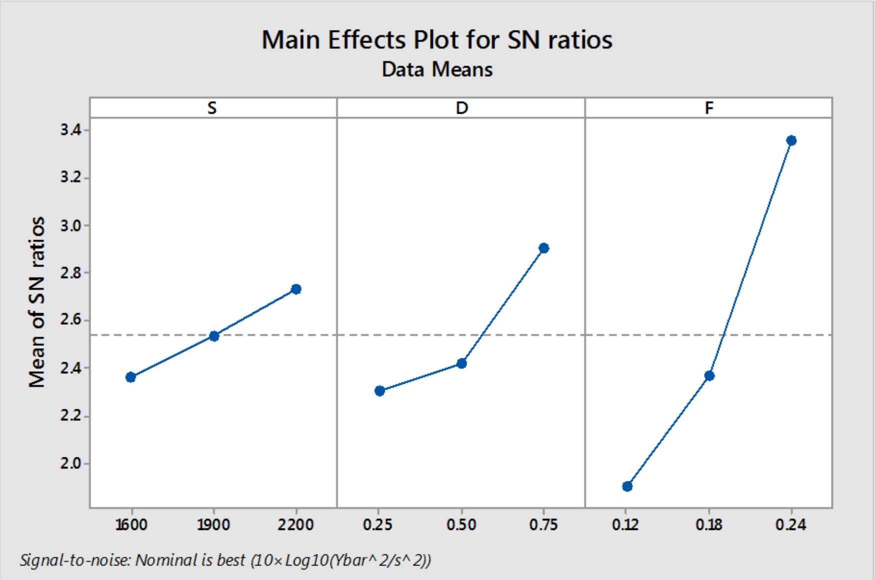

Fig. 4: Main Effects Plot for SN Ratios

In order to quantify the influence of process parameters and interactions on the selected machining characteristic, analysis of variance (ANOVA) was performed as given in Table 6 and Table 7.

Table 6: Analysis of Variance for SN Ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	0.20256	0.20256	0.10128	2.11	0.322
D	2	0.61077	0.61077	0.30539	6.35	0.136
F	2	3.33902	3.33902	1.66951	34.71	0.028
Residual Error	2	0.09620	0.09620	0.04810		
Total	8	4.24856				

Estimated Model Coefficients for SN ratios

S = 0.2193   R-Sq = 97.7%   R-Sq (adj) = 90.9%

Table 7: Analysis of Variance for Standard Deviations

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	0.3718	0.3718	0.1859	0.95	0.512
D	2	0.8364	0.8364	0.4182	2.14	0.318
F	2	10.6115	10.6115	5.3058	27.17	0.036
Residual Error	2	0.3906	0.3906	0.1953		
Total	8	12.2104				

Estimated Model Coefficients for Standard Deviation
S = 0.4419   R-Sq = 96.8%   R-Sq (adj) = 87.2%

It is evident that speed, depth of cut and feed are significant at 95% confidence level and thus affects mean value and variation around the mean value of the Ra. The speed is most significant and thus affects the mean value of the Ra. Next significant factor is depth of cut followed by feed.

The response table for signal noise ratios and for means has been given in Table 8 and Table 9 respectively. The response tables explain that feed is dominant factor followed by depth of cut and speed.

Table 8: Response Table for Signal to Noise Ratios Nominal is best (10×Log10(Ybar^2/s^2))

Level	S	D	F
1	2.365	2.308	1.901
2	2.537	2.419	2.371
3	2.732	2.908	3.362
Delta	0.367	0.600	1.461
Rank	3	2	1

Table 9: Response Table for Means

Level	S	D	F
1	4.575	3.627	2.501
2	3.938	4.084	3.420
3	4.105	4.906	6.697
Delta	0.637	1.279	4.196
Rank	3	2	1

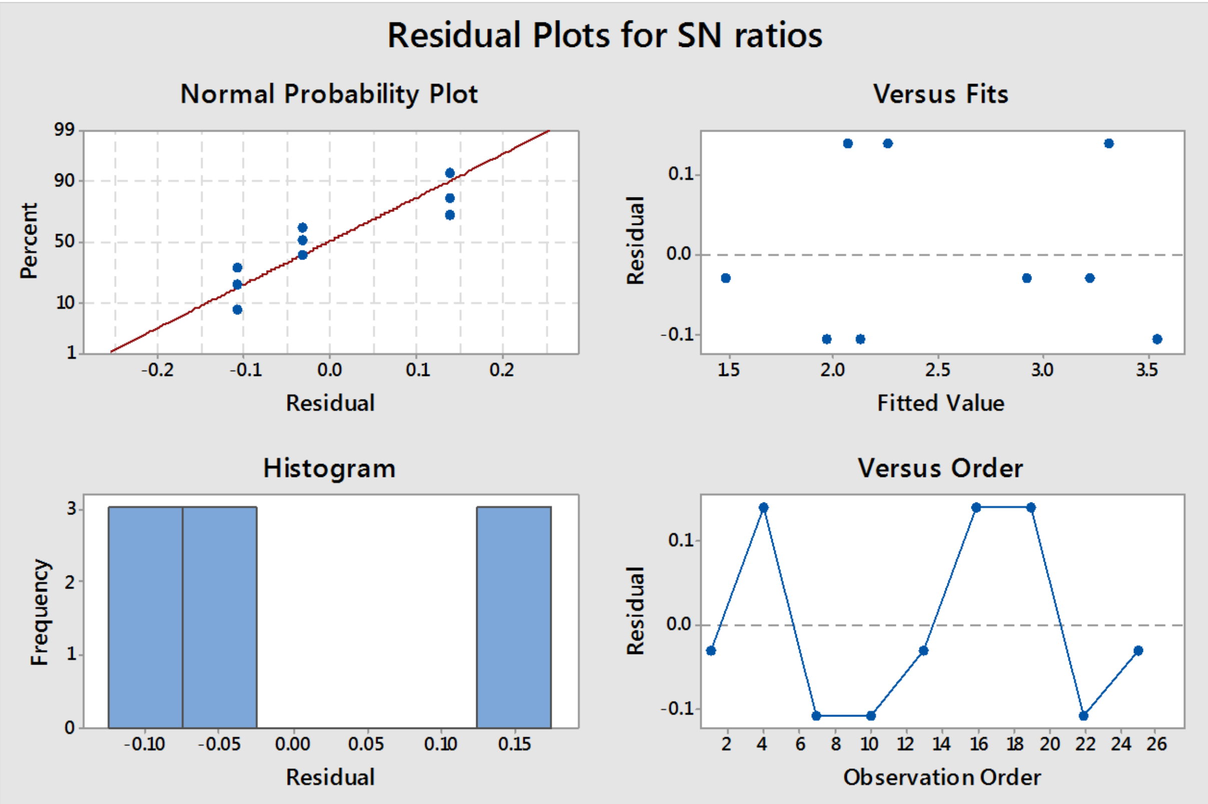

Fig. 5: Residual Plots for SN Ratios

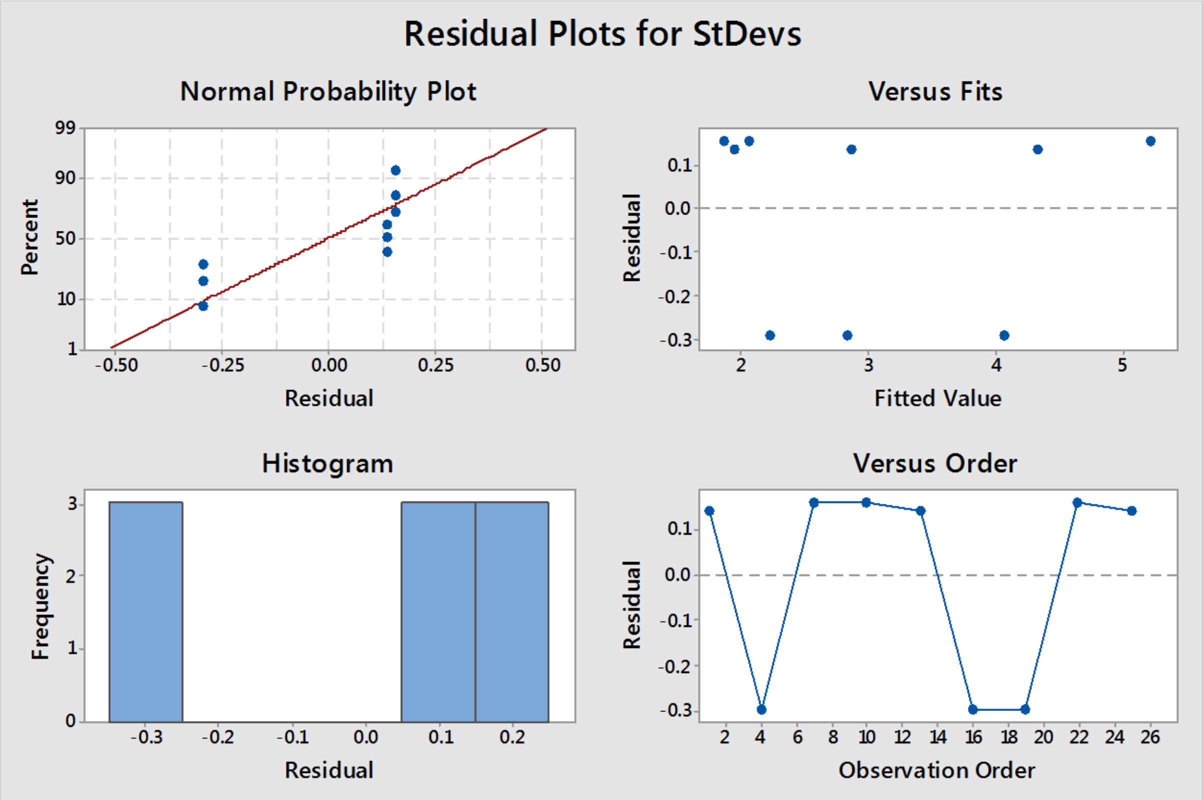

Fig. 6: Residual Plots for Standard Deviations

The diagnostic checking has been performedthrough residual analysis for the developed model.The residual plots for SN Ratios and Standard Deviations are shown inFig. 5 and Fig. 6 respectively. These generally fall on a straight line implying that errors are distributed normally. It can be concluded that allthe values are within the control range, indicating thatthere is no obvious pattern and unusual structure andalso the residual analysis does not indicate any modelinadequacy. Hence these values yield better results infuture predictions.

V. CONCLUSIONS

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extent. The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- CNC Turning gives better results, as speed and feed can be set at any value within a specified range, according to the requirement, compared to a conventional machine in which only some fixed values can be selected.
- Better results have been obtained in terms of DOE techniques such as Taguchi using MINITAB software.
- Increase in cutting speed decreases the surface roughnessup to a certain extent, but as speed increases beyond a certain limit, the surface roughness increases.
- Increase in feed rate adversely affects the surface finish slightly, but a large increase deteriorates surface finish to a large extent.
- ANOVA and F-test revealsthat the speed is dominant parameter followed bydepth of cut and feed.
- The optimal combination process parameters for the work piece under consideration with regards to minimum surface roughness or maximum surface finish is obtained at speed 1900 rpm, depth of cut 0.25 mmand feed rate 0.12 mm/rev.

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