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Research paper



Optimum Selection of Process Parameters in EN-31Alloy Steel for Surface Roughness and MRR using Taguchi Method

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Abstract

Surface roughness and material removal rate (MRR) plays a vital role for precision manufacturing as well as for better productivity. The process parameters such as cutting speed ,feed rate and depth of cut has been optimized on CNC Lathe for the response surface roughness and material removal rate using Taguchi method .The experiments have been conducted on EN-31 alloy steel using L9 (3^3) orthogonal array. The performance characteristics of process parameters have been seen by using analysis of variance (ANOVA) for minimum surface roughness and maximum material removal rate (MRR).The result divulge that the cutting speed has more influential effect on surface roughness of EN-31 steel alloy followed by feed rate and has minimum effect of depth of cut on the same. Whereas it has been seen that, in case of material removal rate depth of cut and feed rate have the more influential effect as compare to the cutting speed. The novelty of this research work lies in the fact that no such study have been carried out by using these process parameters in the archival literature. The Grey relational analysis (multi-objective optimization) technique was employed to optimize the response factors. The optimum process parameters condition was found as cutting speed 2000 rpm, feed rate 200 mm/rev and depth of cut 0.8mm.

Keywords: *Analysis of Variance, EN-31alloy steel, Grey relational analysis, Signal to noise (S/N) ratio, surface roughness, Taguchi Method,*

1. Introduction

Today, there are keen competitions in every field of life, such as in business, educations, and industries and in some other various fields. In manufacturing industries it is not enough to increase productivity but also have to emphasize on best quality of product in terms of surface finish, aesthetic, close tolerance, precision, accuracy etc. for fulfillment of the customers need terms as customers satisfaction.

In the process of metal cutting surface finish is very important response to define the quality. It not only convince the quality, but also economical for manufacturing cost. Tolerance is possible by good surface finish only. It reduces the need of secondary operation as well as assembly time and causes overall cost reduction due to reduction in operation time [1].

Turning is the process of removal of undesired material from a cylindrical work – piece with the help of cutting tool harder than the work material for achieving good surface finish and dimensional tolerances. Material is removed in the form of chips by the action of the tool forces on the work piece and it is only possible when work material is reached on plastic stage. It can be performed on CNC Lathe or on conventional Lathe machines. It is a secondary manufacturing process for getting close dimensional tolerances, good surface finish of casting and forming products [2]. surface roughness have great effect on friction,wear and lubrication of contacting bodies[3]. K. palani kumar et al. [4] found that feed rate has more effect on surface roughness (Ra) among three basic porocess parameters namely cutting speed ,depth of cut and feed rates followed by cutting speed by using response surface methodology (RSM).Nalbant et al.[5] investigated optimized cutting process parameters while turning AISI 1030 steel bars o CNC Lathe using TAGUCHI method.they calculated center line average (CLA) roughness parameters (Ra) only. Also suggested that for better surface finish more insert radius, low feed rate and low depth of cut should be used. Dilbag Singh et al.[6] create a mathematical model for center line average(CLA) to optimize the tool geometry and cutting parameters for hard turning using Genetic Algorithm.

Sayak Mukherjee et al. [7] have optimized the cutting process parameters for maximization of material removal rate (MRR) of SAE 1020while turning in CNC Lathe using Taguchi Technique. Meng et al. [8] have investigated optimize cutting parameters for turning operation using a machining theory. Hen et al. [9] have found condition for better surface finish while turning cylindrical work piece.Negrete et.al. [10] have tried to optimize cutting process parameters for minimum power consumption.Cayda et al. [11] have investigated the effect of variation of cutting tool on machinability of AISI 4340 steel.D.I.Lalwani et al. [12] found the effect of cutting parameters on surface roughness and cutting forces while turning of MDN250 steel using coated ceramic tool on CNC turning. Ashvin J. Makadia et al.[13] have investigated the effect of turning process parameters like feed rate, depth of cut, speed and nose radius on the surface roughness of AISI 410 steel while turning on CNC Lathe by using Design of experiments(DOE).

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2. Material and Method

2.1.Section headings

The cylindrical work piece EN-31 steel alloy is turned on Slant Bed CNC Lathe(LT-16) with high –performance equipped with 8 station bi-directional tool turret,Siemens 828D controller and robot integration features for multi axis heavy machining (Fig.2). 150 mm in length and 32 mm in diameter bar is used for the experiment. Due to having good wear resistance and high strength it has a great application in various field, such as Automobile sector, aerospace and many more. roller and ball bearing, airplane and engine crankshafts, connecting rods, gudgeon pins and gears are some popular components made from this The chemical compositions of EN-31 steel alloy(Fig. 1) are given in table :1

Table 1: Chemical Composition Of EN-31 Steel Alloy

ENseries	C%	Si%	Mn%	Cr%	Mo%
EN31	0.9-1.2	0.1-0.35	0.3-0.75	1-1.6	-



Fig.1: Specimen sample of EN31 steel alloy



Fig. 2: Slant Bed CNC Lathe (LT-16)

The work samples were turned using tungusten carbide tip tool in dry condition at different values of process parameters like cutting speed(v) ,depth of cut(d) and feed rate(f).The different values of process parameters were 1000,1500, 2000 rpm spindle speeds,0.3, 0.5,0.8 mm depth of cut and 100,150, 200 mm/min feed rate used for different samples.these values were selected from standard tables given for the safe operation of material to avoid excessive tool wear and tool failure.

3. Design of Experiment

It is very important statistical tool for performing the experimental study. The experiments are conducted using the Taguchi method. It uses the orthogonal arrays of L9 (33) for experimentation. This design has nine sets of experiments along with nine degree of freedom. The cutting process parameters are cutting speed, feed rate and depth of cut. The beauty of this design method is that its uses very less numbers of experiments and gives best results. The control variables and their levels for achieving desired responses are given in Table: 2.

Table: 2 machining process Parameters and their levels

Control factors		Levels		
	Codes	Level 1	Level 2	Level 3
Spindle speed(rpm)	A	1000	1500	2000
Depth of cut (mm)	B	0.3	0.5	0.8
Feed rate(mm/min)	C	100	150	200

3.1. Experimental Steps

Experiments were carried out by using nine cylindrical bar of EN-36 alloy steel of the same dimensions at different specified process parameters. Every work-piece was turns at a fixed marks length. The initial and final diameter of each sample was measured before and after the turning operation on CNC Lathe. After completing of all experiments on CNC Lathe the work piece was removed from setup and response variable such as surface roughness and material removal rate (MRR) was measured. Average arithmetic roughness (Ra) also called centre line average; root mean square roughness (Rq) and maximum peak to valley height (Rz) are the main parameters for measuring the surface roughness. Out of these average arithmetic roughness (Ra) is most popular parameter for measuring the surface roughness. In this experiment surface roughness was measured by Surfcom flex 50A shown in Fig-3. Surfcom flex 50A consists of 50 mm tracing driver, small tracing driver, available skidless measurement and waviness measurement. Material removal rate is noted down of each work piece after turning operations. It is the material removal rate per unit time. the experiments results for response variables are given in table no:



Fig .3 SURFCOM FLEX -50A

Table 3: Experimental results of Surface roughness and MRR

Exp.no.	Cutting speed rpm	DOC (mm)	F(mm/min)	Roughness,Ra (µm)	Roughness,Rz (µm)	MRR (mm^3/sec)
1	1000	0.3	100	2.05	9.21	41.56
2	1000	0.5	150	1.25	10.10	58.80
3	1000	0.8	200	1.20	4.80	79.00
4	1500	0.3	200	1.49	8.44	48.54
5	1500	0.5	100	1.00	4.28	75.00
6	1500	0.8	150	0.89	2.80	57.58
7	2000	0.3	150	0.94	1.97	43.25
8	2000	0.5	200	0.81	1.85	57.80
9	2000	0.8	100	0.67	1.82	70.00

4. Results and Discussions

4.1. Analysis of Surface Roughness (Ra) and(Rz)

The surface roughness data which are obtained from experimentation have been analyzed by signal to noise ratios S/N method by using Taguchi statistical tool. With the help of MINITAB software S/N ratio was calculated by applying smaller

is the better criterion. This criterion is selected because motto is to minimize the surface roughness (Ra) and (Rz). For minimum surface roughness the value of signal to noise ratio (S/N) should be maximum which can be easily seen in table no: 4

In Table: 4 the value of MRR has been shown on the basis of experiments which were carried out on the CNC Lathe. For maximum material removal rate (MRR), signal to noise ratio (S/N) should be maximum corresponding to the optimize process parameters which could be seen on the table easily.

4.2 Analysis of Variance (ANOVA) for R_a, Rz and MRR

It is a statistical technique that is used to check if the means of two or more groups are significantly different from each other. It checks the impact of one or more factors by comparing the means of different samples. It is used to found the most effective process parameters (speed, feed rate and depth of cut) over response parameter (surface roughness, MRR). The result of S/N ratio for surface roughness (R_a) has been calculated with the help of MINITAB software by using general linear model of ANOVA which is shown in Table: 5. It has been seen from the ANOVA table that cutting speed has the best parameters for the minimization of surface roughness since its percentage contribution is highest 50.31980% amongst the main parameters followed by the feed rate having the percentage contribution of 40.04588% and depth of cut has very less percent.

contribution of 4.645252% means very less effective in surface roughness. The error percentage contribution of 4.645252% reveals that there are some other control factors apart from the main process parameters such as environment condition (temperature, pressure, and humidity), vibration and cutting forces which affects the response parameters. Percentage contribution of control factors along with the error for the surface roughness (R_a) is shown in pie chart of Fig.4.

ANOVA Table of the regression model of surface roughness (Ra) is shown in Table: 6. In this the value of F tabulated 14.77 which is more than the value of $F_{3,5,\ 0.01\ =12.060}$ hence the model is adequate and lies within the confidence interval (CI) of 99%.

Similarly the ANOVA table for surface roughness (R_z) is shown in Table:7 in this the most significant process parameters are in the sequence of cutting speed ,feed rate and depth of cut having the percentage contribution of 63.1582%,19.9745% and16.8295% respectively. The Error percentage contribution of 3.7677% shows that there are some other control factors which affecting the response parameters. Percentage contribution of control factors along with the error is shown in pie chart of Fig.4.

Table4: Experimental results for Surface roughness, MRR and S/N ratio

	Control factors			Roughness,Ra (µm)	Roughness,Rz (µm)	MRR (mm^3/sec)	S/N Ratio[dB] for Ra	S/N Ratio[dB] for Rz	S/N Ratio [dB] for MRR
	Speed (rpm)	DOC (mm)	F(mm/min)						
1	1000	0.3	100	2.056	9.216	41.56	-6.26046	-19.2908	32.3735
2	1000	0.5	150	1.25	10.102	62.8	-1.93382	-20.0881	35.9592
3	1000	0.8	200	1.2	4.8	79	-1.58362	-13.6248	37.9525
4	1500	0.3	200	1.497	8.442	60.54	-3.50444	-18.5289	35.6408
5	1500	0.5	100	1	4.288	75	0	-12.6451	37.502
6	1500	0.8	150	0.897	2.8	57.58	0.94415	-8.94432	35.2054
7	2000	0.3	150	0.945	1.971	65.25	0.49136	-5.89937	36.2916
8	2000	0.5	200	0.819	1.85	57.8	1.73432	-5.34434	35.2386
9	2000	0.8	100	0.676	1.82	66.45	3.40107	-5.20149	36.4499

ANOVA Table of the regression model of surface roughness (R_z) is shown in Table: 8. In this the value of F tabulated 8.09 which is more than the value of F3, 5, 0.025 = 7.7636 hence the model is adequate and lies within the confidence interval (CI) of 97.5%.

4.3 Analysis of Variance (ANOVA) for MRR

The ANOVA table for material removal rate (MRR) is shown in Table: 10 It has been seen from the ANOVA table that depth of cut has the best parameters for the maximization of MRR since its percentage contribution is highest 68.9786% amongst the main parameters followed by the feed rate having the percentage contribution of 25.1600% and cutting speed has very less percent contribution of 1.7283 % means very less effective in MRR. The error percentage contribution of 4.1340 % reveals that there are some other control factors apart from the main process parameters such as environment condition (temperature, pressure, and humidity), vibration and cutting forces which affects the response parameters. Percentage contribution of control factors along with the error for the material removal rate MRR is shown in pie chart of Fig.8.

Table 5: Analysis of Variance for Surface roughness Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	Percentage contribution
Speed	2	0.71278	0.71278	0.35639	10.09	50.31
Feed rate	2	0.56725	0.56725	0.28363	8.03	40.04
Depth of cut	2	0.06580	0.06580	0.03290	0.93	4.64
Error	2	0.07067	0.07067	0.03534		4.98
Total	8	1.41650				

Ra(µm) = 3.26 - 0.000689 Speed - 0.00575 Feed - 0.409 DOC (1)

S = 0.170580 R-Sq = 89.7% R-Sq(adj) = 83.6%

Table 6: ANOVA Table of the regression model of Ra

Source	DF	SS	MS	F	P	$F_{,3,5,\ 0.01\ =12.060}$
Regression	3	1.27285	0.42428	14.77	0.006	F> $F_{,3,5,0.01}$ hence model is adequate
Residual Error	5	0.14365	0.02873			
Total	8	1.41650				

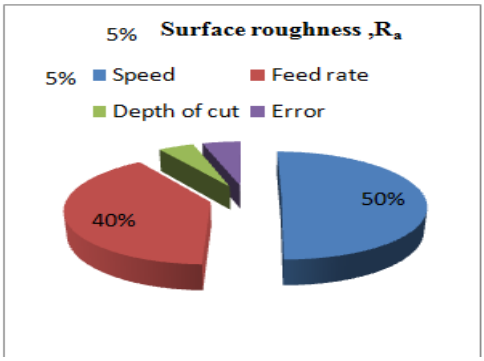


Fig.4: Pie chart of control factors contribution for Ra

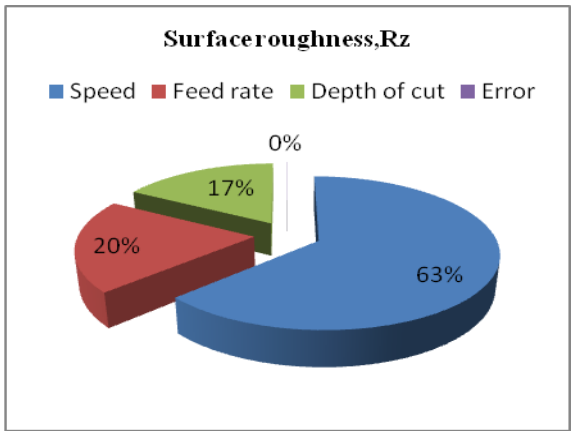


Fig.5: Pie chart of control factors contribution for R_z

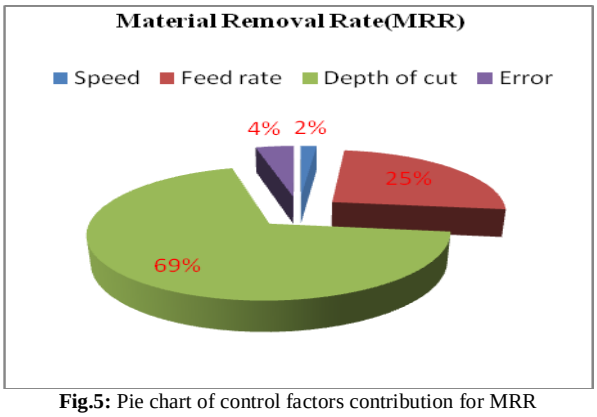


Fig.5: Pie chart of control factors contribution for MRR

Table 7: Analysis of Variance for surface Roughness Rz

Source	DF	Seq SS	Adj MS	F	P	% contribution
Speed	2	56.99	28.49	1680.76	0.001	63.1582
Feed rate	2	18.02	9.012	531.55	0.002	19.9745
Depth of cut	2	15.2	7.594	447.88	0.002	16.8295
Error	2	0.03	0.017			3.7677
Total	8	90.2				

$$R_z = 18.0 - 0.00616 \text{ Speed} - 6.87 \text{ F} - 0.0008 \text{ DOC} \quad (2)$$

Table 8: ANOVA Table of the regression model of R_z

Source	DF	SS	MS	F	P	F3,5,0.025 = 7.7636
Regression	3	74.828	24.943	8.09	0.023	F> F,3,5,0.025 hence model is adequate
Residual Error	5	15.412	3.082			
Total	8	90.240				

Table 9: Analysis of Variance for MRR, using Adjusted SS for Tests

Source	**DF**	**Seq SS**	**Adj MS**	**F**	**P**	**Percentage contribution**
Speed	2	16.23	8.11	0.42	0.705	1.7283
Feed rate	2	236.26	118.13	6.09	0.141	25.1600
Depth of cut	2	647.73	323.86	16.69	0.057	68.9786
Error	2	38.82	19.41			4.1340
Total	8	939.03				

$$MRR = 28.2 + 1.02 \text{ Speed} + 5.95 \text{ F} + 10.4 \text{ DOC} \quad (3)$$

Table 10: ANOVA table of regression model for MRR

Source	**DF**	**SS**	**MS**	**F**	**P**	**F3,5,.001=12.060**
Regression	3	865.55	288.52	19.63	0.003	F> F,3,5,0.001 hence model is adequate
Residual Error	5	73.48	14.70			
Total	8	939.03				

4.4 Main Effect Plots for Surface Roughness of R_a , R_z and MRR

The main effect plots for surface roughness R_a,R_z and material removal rate MRR have been shown in Fig.6, Fig.7and Fig.8 respectively. Basically it is the plots between means of S/N ratio and process parameters. From Fig.6, Fig.7 it could be clearly seen that as the cutting speed is increases the signal to noise ratio S/N increases. It can be clearly seen that S/N ratio is changes steeply and curve is almost straight means its effect is more in turning process for surface roughness. Similarly in case of feed rate S/N ratio is first gradually increases after then steeply but less than the cutting speed which shows the less involvement of feed rate than the speed. But in case of depth of cut S/N ratio deceases sharply after then increases gradually making V shape in surface roughness (R_a) shows very less impact on the surface roughness as compare to the speed and feed rate, whereas in case of R_z it effect is also very less but S/N ratio is gradually increases.
Similarly main effect plots for MRR has been explain from the Fig.8.It can be easily seen that there is steep increase in the S/N ratio when depth of cut is increase, this shows the major contribution in material removal rate, while in case of feed rate S/N ratio is firstly increases steeply, after then gradually mean effect is less as compare to the depth of cut similarly for cutting speed S/N ratio first increases gradually after then increases slowly means it impact is very less as compare to the depth of cut and feed rate for MRR. So here optimize process parameter for MRR are in the sequence of depth of cut, feed rate and cutting speed.

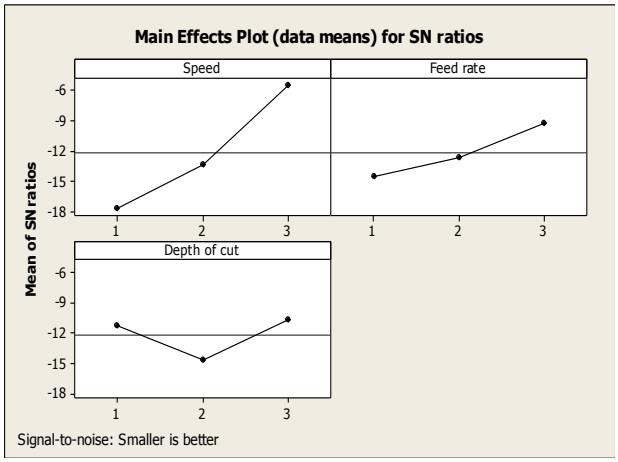


Fig. 6: Main effect plots for Surface roughness, Ra

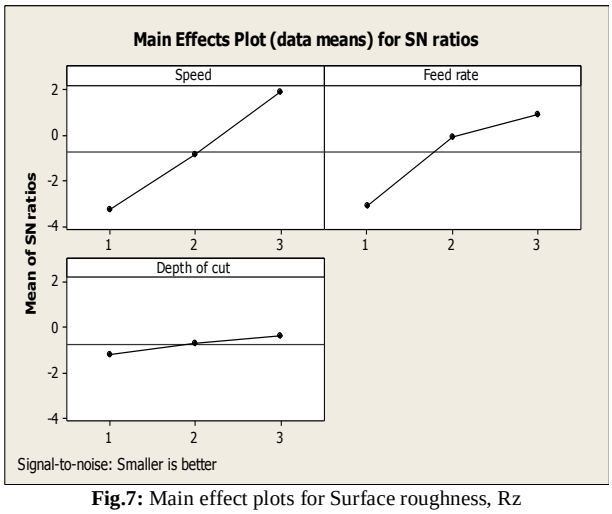


Fig.7: Main effect plots for Surface roughness, Rz

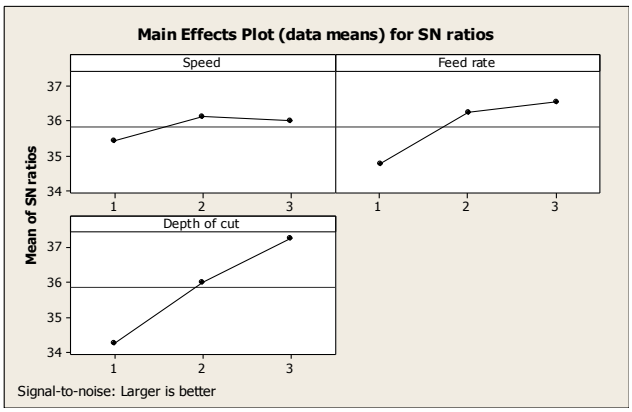


Fig.8: Main effect plots for Material Removal Rate, MRR

Table 11: Optimum Condition for surface roughness and MRR

Factors	Optimum condition for SR	Optimum condition for MRR	Model value of SR Ra,,Rz	Experimental value of SR	Model value of MRR	Experimental value of MRR
Speed (rpm)	2000	1500	0.4038 ±.1060 (0.2978-0.5098), 0.244 ±.000559 (0.2384 – 0.244559	0.282,	80.31±1.9018 (78.4082 – 82.211)	79.00
Feed rate(mm/revolution)	200	200				
Depth of cut(mm)	0.8	0.8				

5. Otimization of Multi – Response Using GRA

Taguchi methods is a statistical tool used for improving the product quality.It is used to optimize the single performance characteristics . According to Phadke (1989), it is impossible to optimize the multi - resposes by using Taguchi method.The GRA theory which has been developed by Deng (1982) is useful for dealing poor and insufficient types of problems.It is the tool which is used to solve the complicated interrelationship among the prescribed responses.Now it is known as powerful tool for optimization of multi characteristics.Many researchers such as (Lin and Lin, 2002; Tarng et al., 2002; Panet al., 2007) have used the grey relational analysis along with Taguchi method for optimizing the multi-response in various fields. In this tool the grey relational grade is calculated for obtaining the multiple performance charecteristics. This tool is utilized for converting multiple performance characteristics into optimization of a single grey relational grade.

Three basic steps of GRA are as follows:

- Data Pre-processing.
- Calculating the grey relational coefficients.
- Calculating the grey relational grade.

5.1. Data Pre-Processing

It is the first steps in GRA.In data pre – processing the original sequence is transformed into a comparable sequence. The results which are obtained after experiments are normalized in the range of 0 -1.The normalization of original series data is obtained by dividing it by their average. Let the $y_0(k)$ and $y_i(k)$ is the original reference sequence and sequence for comparison respectively, where i = 1,2,…..m ; k = 1,2,……..,n; here m is the total no. of experiments and n is the total no. of observations data. Pre- processing data can be used in several ways in Grey relation analysis, on the basis of original sequence characteristics (Deng, 1989; You et al., 2007).

If the desired value of the original sequence is "larger-the-better", then the original sequence is normalized as follows:

$$Y_i^*(k) = \frac{Y^0{}_i(k) - \min Y^0{}_i(k)}{\max Y^0{}_i(k) - \min Y^0{}_i(k)} \quad (3)$$

If the original sequence is "smaller-the-better", then it normalizes as follows:

$$Y^*{}_i(k) = \frac{\max Y^0{}_i(k) - Y^0{}_i(k)}{\max Y^0{}_i(k) - \min Y^0{}_i(k)} \quad (4)$$

For "a specific target value" the original sequence normalizes as below:

$$Y^*{}_i(k) = \frac{\text{/}^{\,0}{}_i(A)\text{Ø}k - Y \quad \text{/}}{\max\{\max Y^0{}_i(k) - OA\,;\; OA - \min Y^0{}_i(k)\}} \quad (5)$$

Where, OA is the target value. In this research paper, S/N ratios of the turning response have been normalized on the basis of "larger-the-better", type response. Thus equation 1 has been utilized for normalizing the data.

Using Table 3, S/N ratios of two turning responses for all 9 sequences have been listed in Table 4.The normalization of S/N ratios using equation 1 has been shown in table no.12.In equation 1: $Y^*{}_i(k)$ is the sequence after the data processing. max $Y^0{}_i(k)$ and min $Y^0{}_i(k)$ is the largest and smallest value of $Y^0{}_i(k)$ respectively.

Table12: Sequence after data pre-processing

No.	MRR	SR(Ra)	SR(Rz)
Reference Sequence ⇨ / Comparability Sequence ⇩	1.0000	1.000	1.0000
1	0	0	0.05355
2	0.64271	0.44736	0
3	1	0.48406	0.43416
4	0.58564	0.28525	0.10473
5	0.9191	0.64797	0.4999
6	0.50759	0.7457	0.7486
7	0.70229	0.6988	0.9534
8	0.19295	0.8274	0.99046
9	0.73086	1	1

5.1 Grey Relational Coefficient:

It is used to calculate for showing the relationship between actual normalized S/N ratio and the best (reference).The equation through which it can be expressed as given below:

$$\zeta_{0,i}(k) = \frac{\Delta_{min} + \gamma.\Delta_{max}}{\Delta_{0,i}(k) + \gamma.\Delta_{max}} \quad (6)$$

$$0 \le \zeta_{0,i}(k) \le 1$$

Where $\Delta 0, i(k)$ is the deviation sequence of reference sequence

Y*0(k) and Y*i (k) is comparability sequence, i.e. Δ0, i(k) = ׀ Y*0(k) - Y*i (k) ׀ give the absolute value .

$$\Delta_{min} = min.min.\ \Delta_{0,i}(k) \quad (7)$$

$$\Delta_{max} = max.max.\ \Delta_{0,i}(k) \quad (8)$$

γ is the distinguishing coefficient γ ϵ ׀0,1׀,γ is set as for 0.5 in this paper. This is used for showing the relational degree between the reference sequences Y*0(k) and the comparability 9 sequencesY*i(k).

Using Table.12, the deviation sequence Δ01 can be calculated as follows:

$$\Delta_{01}(1) = |1.0000 - 0.0000| = 1.0000$$
$$\Delta_{02}(2) = |1.0000 - 0.0000| = 1.0000$$
$$\Delta_{03}(3) = |1.0000 - 0.05355| = 0.9645$$

Thus $\Delta_{01} = (1.0000,\ 1.0000, 0.9645)$

Thus adopting the same procedure for i=(1-9) and the results of all $\Delta_{0i}\ i = 1-9$ has been listed below in Table 13.

Table 13: The deviation sequences

Deviation Sequences	$\Delta_{01}(1)$	$\Delta_{01}(2)$	$\Delta_{01}(3)$
No. 1, *i* =1	1	1	0.9645
No. 2, *i* =2	0.35729	0.55264	1
No. 3, *i* =3	0	0.5159	0.5658
No. 4, *i* =4	0.4144	0.7148	0.8953
No. 5, *i* =5	0.0809	0.3521	0.50003
No. 6, *i* =6	0.4924	0.2543	0.2513
No. 7, *i* =7	0.2077	0.3012	0.0466
No. 8, *i* =8	0.8071	0.1725	0.0096
No.9 , *i* =9	0.2691	0	0

By observing the data listed in the table .13 we can find that $\Delta_{max}(k)\ and\ \Delta_{min}(k)$ are as follows:

$$\Delta_{max} = \Delta_{01}(1) = \Delta_{01}(2) = \Delta_{02}(3) = 1.0000$$
$$\Delta_{min} = \Delta_{03}(1) = \Delta_{09}(2) = \Delta_{09}(3) = 0.0000$$

The grey relational coefficient $\zeta(Y^*_0(k).\ Y^*_i(k))$ can be calculated Using table.13 and equation 4 given as follows:

$$\zeta(Y^*_0(1).\ Y^*_1(1)) = \frac{0.0000 + 0.5 \times 1.0000}{1.0000 + 0.5 \times 1.0000} = 0.3333$$

$$\zeta(Y^*_0(2).\ Y^*_1(2)) = \frac{0.0000 + 0.5 \times 1.0000}{1.0000 + 0.5 \times 1.0000} = 0.3333$$

$$\zeta(Y^*_0(3).\ Y^*_1(3)) = \frac{0.0000 + 0.5 \times 1.0000}{0.9645 + 0.5 \times 1.0000} = 0.3414$$

Therefore

$$\zeta(Y^*_0(k).\ Y^*_i(k)) = (0.3333,\ 0.3333,\ 0.3414),\ k = 1-3$$

Table14: Grey relational coefficients and grade value

No. (Comparability sequence)	MRR	SR(Ra)	SR(Rz)	Grade value
1	0.3333	0.3333	0.3414	0.336
2	0.5832	0.4749	0.3333	0.4638
3	1.0000	0.4921	0.4691	0.6537
4	0.5468	0.4115	0.3583	0.4388
5	0.8607	0.5867	0.909	0.7854
6	0.5038	0.6628	0.6655	0.6107
7	0.7065	0.624	0.9147	0.7484
8	0.3825	0.7434	0.9811	0.7023
9	0.6501	1.0000	1.0000	0.8833

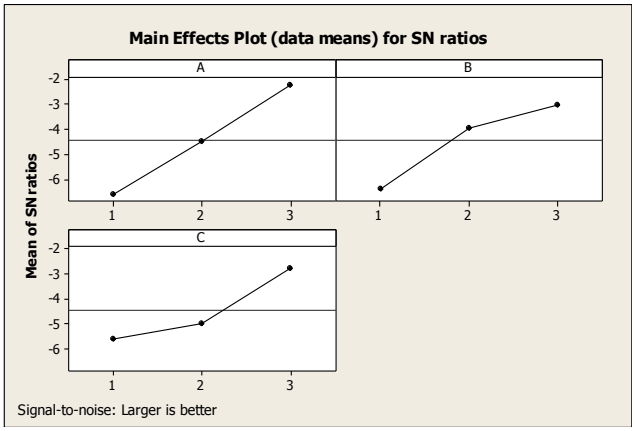


Fig.10: Main effect plots for Grey relational grade.

It can be seen from the main effect plot of Grey relational grade, that cutting speed, feed rate have the more influential effect than depth of cut and its values have been found as cutting speed 2000 rpm, feed rate 200 mm/rev and depth of cut 0.8 mm. ANOVA table for Grey Relational Grade has been shown in table no. 15.

Table15: ANOVA table for Grey Relational Grade

Source	DF	Seq SS	Adj MS	F	P
A	2	0.129983	0.064992	15.02	0.062
B	2	0.067993	0.033996	7.86	0.113
C	2	0.052223	0.026111	6.03	0.142
Error	2	0.008655	0.004328		
Total	8	0.258854			

S = 0.0657854 R-Sq = 96.66% R-Sq (adj) = 86.63%

6. Conclusions

This paper investigates the optimization of process parameters (cutting speed, feed rate and depth of cut) while turning the EN31alloy steel on CNC Lathe for minimizing surface roughness and maximizing the material removal rates. It utilizes the Taguchi L9 (3^3) orthogonal array design along with ANOVA for finding effective process parameters of the response parameters and their importance in machining. The findings of this paper are listed below.

- The minimum surface roughness (CLA value) has been found as 0.282µm and Peak to valley height surface roughness value as 1.82 µm at optimum turning process parameters of cutting speed as 2000 rpm, feed rate 200 mm/rev and depth of cut of 0.8 mm.
- It has been observed from ANOVA table that the cutting speed has been found as most influencing process parameter for minimization of surface roughness and its percentage contribution factor is found as 50.31980% and 63.1582% for Ra and R_z respectively while feed rate having percentage contribution as 40.04588% and 19.9745% for Ra and R_z respectively.
- The F value found as 14.77 from ANOVA Table of the regression model of R_a has more value than the tabulated value $F_{, 3, 5, 0.01}$ as 12.06 which show that it lies within the confidence interval of 99%. Hence the model is found adequate.
- The F value found as 8.09 from ANOVA Table of the regression model of R_z has the more value than the tabulated value

$F_{3, 5, 0.025}$ as 7.7636 which shows that it lies within the confidence interval of 99%.Hence the model is found adequate.

- The maximum material removal rate (MRR) has been found as 80.31 mm^3/sec at optimum process parameters of depth of cut of 0.8mm, feed rate 200 mm/min and cutting speed 2000 rpm.
- It has been observed from ANOVA table that the depth of cut has been found as most influencing process parameter for maximization of material removal rate (MRR) and its percentage contribution factor is found as 68.9786% while feed rate having percentage contribution as 25.1600%.
- The result of F = 19.63 obtained from ANOVA Table of the regression model of MRR has the more value than the F3,5,.001=12.060 shows that it lies within the confidence interval(CI) of 99.9%.hence the model is adequate.
- Thus the optimization process parameters for surface roughness and MRR are obtained as cutting speed 2000 rpm, feed rate 200 mm/rev, depth of cut 0.8 mm,and cutting speed 1500 rpm, feed rate 200 mm/rev and depth of cut 0.8 mm respectively.
- Thus the cutting process parameters at optimization of multi-responses has been found as cutting speed 2000 rpm, feed rate 200 mm/rev and depth of cut 0.8 mm using GRA and Taguchi method.

References

[1] Kumar NS, Shetty A, Shetty A, K A & Shetty H(2012), Effect of spindle speed and feed rate on surface roughness of Carbon Steels in CNC turning. International Conference on Modeling Optimization and Computing (ICMOC 2012),Procedia Engineering 38, 691 – 697.

[2] Gowd GH, Goud MV , Theja KD & Reddy MG(2014), Optimal Selection Of Machining Parameters In CNCTurning Process Of EN-31 Using Intelligent Hybrid DecisionMaking Tools. Procedia Engineering 97, 125 – 133.

[3] Lee and Ren SC,Lee & N Ren(1996) Behaviour of elastic-plastic rough surface contacts as affected by surface topography, load and material hardness.Tribol Trans. 39 (1) 1996, pp.67-74.

[4] kP,& RK(2007), optimal machining condition for turning of particulates metal matrix composite using Taguchi and response surface methodologies. Machining Science and Technology,An International journal. 104,17-433.

[5] MN, HG& GS(2007), Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Materials and Design. 28,1379-1385.

[6] Dilbag S & Rao PV (2007),Optimization of Tool Geometry and Cutting Parameters for Hard Turning. Material and Manufacturing Processes.22,15-21.

[7] Mukherjee S, Kamal A, Kumar(2014),Optimization of Material Removal Rate During Turning of SAE 1020Material in CNC Lathe using Taguchi .Technique.Procedia Engineering .97 , 29 – 35.

[8] Q M(2000),Calculation of optimum cutting condition for turning operation using a machining theory. Int. J. Mach. Tool Manuf. 40, 1709–1733.

[9] Chen M.C& Su (1998), Optimization of machining conditions for turning cylindrical stocks into continuous finished profiles. Int. J. Prod. Res. 36(8), 2115–2130.

[10] Negrete CC, Nájera JC & ValenzuelaJCM(2013), Optimization of Cutting Parameters in Turning of AISI 1018 Steel With Constant Material Removal Rate Using Robust Design for Minimizing Cutting Power. Paper No. IMECE 2013-62520,

[11] U C(2010, Machinability evaluation in hard turning of AISI 4340 steel with different cutting tools using statistical techniques. PROC INST MECH ENG B-J ENG MA 01/2010; 224(7):1043-1055. DOI: 10.1243/09544054JEM1822.

[12] LalwaniDI, MehtaNK, JainPK(2008), Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel. Journals of material processing technology206,167-179.

[13] Makadia AJ, Nanavati JI(2013),Optimizations of machining parameters for Turning operations based on response surface methodology. *Measurement 46 ,1521-1529.*

[14] PhadkeMS(1998), Quality Engineering Using Robust Design.Prentice Hall: Englewood Cliffs, NJ,

[15] LinJL & TarngYS(1998), Optimization of the multi-response process by the Taguchi method with greyrelational analysis. Journal of Grey System10(4), 355 – 370.