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Parametric Optimization & Modeling for Surface Roughness, Feed and Radial Force of EN-19/ANSI-4140 Steel in CNC Turning Using Taguchi and Regression Analysis Method

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ABSTRACT

Efficient turning of high performance EN series material can be achieved through proper selection of turning process parameters to minimize surface roughness, feed and radial forces. In this present paper outlines an experimental study to optimize and study the effects of process parameters in CNC turning on Surface roughness, feed and radial forces of EN19/AISI4140 (medium carbon steel) work material in dry environment conditions. The orthogonal array, signal to noise ratio and analysis of variance are employed to study the performance characteristics in CNC turning operation. Three machining parameters are chosen as process parameters: Cutting Speed, Feed rate and Depth of cut. The experimentation plan is designed using Taguchi's L9 Orthogonal Array (OA) and Minitab-16 statistical software is used. Optimal values of process parameters for desired performance characteristics are obtained by Taguchi design of experiment. Prediction models are developed with the help of regression analysis method using Minitab-16 software and finally the optimal and predicted results are also verified with the help of confirmation experiments.

Keywords- Taguchi method, surface roughness, feed and radial force, CNC turning, regression modeling.

1. INTRODUCTION

Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry; there has been increased interest in monitoring all aspects of the machining process. Turning is the most widely used among all the cutting processes. The finished component is subjected to dimensional accuracy, required surface finish; the tool is subjected to less force, minimum possible temperature and maximum tool life; and Process is subjected to high material removal rate. In order to achieve these desired performance measures in any machining operation, proper selections of machining parameters are very essential. The present method of selection of machining parameters of machining parameters by trial and error, previous work experiences of the process planner and machining data hand books are very time consuming and tedious process. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts. [7]

EN19 is a medium-carbon steel and finds its typical applications in the manufacturing of automobile and machine tool parts such as gears, shafts, spindles, etc. Properties of EN19 steel, like low specific heat, and tendency to strain-harden and diffuse between tool and work material, give rise to certain problems in its machining such as large forces, high cutting-tool temperatures, poor surface finish and built-up-edge formation. This material is thus difficult to machine. [1].

Taguchi proposes an off-line strategy for quality improvement in place of an attempt to inspect quality into a product on the production line. He observes that no amount of inspection can put quality back into the product; it merely treats a symptom. To achieve desirable product quality by design, Taguchi recommends a three stage process: system design, parameter design and tolerance design. While system design helps to identify the working levels of the design parameters, parameter design seeks to determine the parameter levels that produce the best performance of the product/process under study. The optimal condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance. The orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design. Tolerance design is a step to fine tune the results of parameter design by tightening the tolerance of parameters with significant influence on the product. [2-3]

The objective of this paper is to obtain optimal settings and study the effect of process parameters-cutting speed, feed and depth of cut, resulting in an optimum value of surface roughness, feed and radial forces while turning En19 steel with uncoated carbide inserts. The effects of the process parameters on desired surface roughness, feed and radial forces and the subsequent optimal settings of the parameters for obtaining optimal value of surface roughness, feed and radial forces have been accomplished using Taguchi's parameter design approach.

2.BACKGROUND OF TAGUCHI METHOD

Dr. Genichi Taguchi is a Japanese statistician and Deming prize winner who pioneered techniques to improve quality through Robust Design of products and production processes. Dr. Taguchi developed fractional factorial experimental designs that use a very limited number of experimental runs. The Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost [3].

Taguchi asserted that the development of his methods of experimental design started in Japan about 1948. These methods were then refined over the next several decades. They were introduced in the United States around 1980. Although, Taguchi's approach was built on traditional concepts of design of experiments (DOE), such as factorial and fractional factorial designs and orthogonal arrays, he created and promoted some new DOE techniques such as signal-to-noise ratios, robust designs, and parameter and tolerance designs.[2]

Basically, experimental design method was developed by Fisher. However, classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristics in analysis of S/N ratio i.e. lower-the-better, higher-the -better, and nominal-the-better.[4] The Signal to noise ratio measures the sensitivity of the quality characteristic being investigated in controlled manner, to those external influencing factors (Noise Factors) not under control. The aim in any experiment is always to determine the highest possible (S/N) ratio for the result irrespective of the type of quality characteristic. A high value of S/N implies the signal is much higher than the random effect of Noise factor. [9]

In this paper our objective is to minimize surface roughness, feed and radial forces then we select lower the better criteria for each response to calculate S/N ratio.

3. EXPERIMENTAL DETAIL

3.1. WORK MATERIAL

The present work deals with the turning of hard material such as EN-19(AISI 4140) steel. This material is chosen because of its wide use in manufacturing machinery parts, gear wheels, tie rods, bolts, pins and shaft requiring high resistance. Since the present trend in the manufacturing industry is high speed dry machining, it is applied to evaluate the performance of uncoated tools in typical manufacturing processes.

Table1: The chemical and mechanical properties of EN-19/AISI 4140 steel [11]

Elements	C %	Si %	Mn %	Cr %	Mo %
Weight %	0.40 %	0.25 %	0.85 %	1.0 %	0.25%
Mech. Prop.	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Hardness (HB)	
	770	930	17	275	

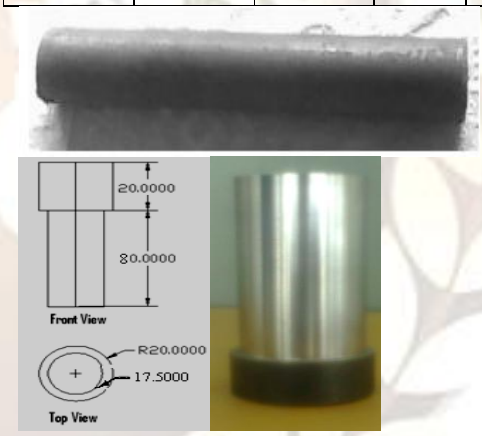


Fig. 1: Photogragh of Full length unfinished rod of EN-19 material, diagram showing dimensions of finished work piece and Photogragh of finished work piece after CNC turning operation.

3.2. SELECTION OF CUTTING TOOLS AND TOOL HOLDERS

The cutting tool selected for machining EN19 steel is uncoated carbide inserts. The specifications of tool geometry and tool holder are as follows:

Cutting Tool Specification:

Tool material-Uncoated carbide tool
Manufactured by-KORLOY Inc.
Tool Designation-TOEH 060102L ST10
T - Insert Shape = 60° , C- Clearance Angle = 7°
Relief angle = 8°, nose radius=0.2 mm

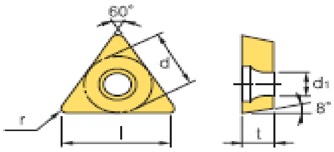


Fig 2: Uncoated carbide tool

Cutting Tool Holder Specification:
Designation -PTTNR/L 2020-K16
L=125 mm, W=20 mm, H=20 mm

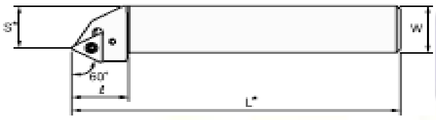


Fig3 cutting tool holder

3.3. EXPERIMENTAL PLAN AND CUTTING CONDITIONS

The experiments are carried out on a CNC turning lathe machine (PRAGA-INDIA RTC 600) in Dry working environment Installed at National Small Industries Corporation L.T.D, Aligarh (U.P.) India. The experimental setup is shown in Fig.4. For the present experimental work the three controllable process parameters with three levels have been taken [12]. The levels of the individual process parameters/factors are given in Table 2.Feed and radial forces are varying over a time span of cutting operation due to the variation of mechanical properties of the work piece, vibrations etc. Therefore considering this as a noise factor in this experimental work, forces are measured three times during the machining process for overcome this variation.

CNC Lathe Machine Specifications:
Type: - CNC Lathe PTC-600
Controller: - Fanuc
Swing Over bed: - 400 mm.
Spindle Power: - 7.5/11 Kw
Turning Length (mm): 300
Rapid Feed (X& Z axis): 24 M/min
Speed Range: 50-4500 rpm

Fig 4: Photograph of PRAGA-INDIA PTC 600 CNC lathe

Table 2: Process variables and their levels

S.No.	Process Parameter	Process Parameter	Levels		
			Low	Medium	High
1.	V	Cutting Speed (m/min.)	100	150	200
2.	f	Feed Rate (mm/rev.)	0.05	0.11	0.17
3.	d	Depth Of Cut (mm.)	0.4	0.8	1.2

Feed force, Radial force acts in the direction of radius of w/p and in the direction of feed of tool both are responsible for causing dimensional inaccuracy and vibration. In the given fig.5 feed force is represent by F_t and radial force is represent by F_f.

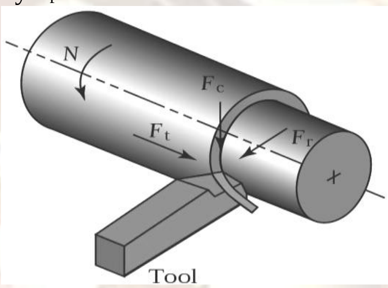


Fig: 5 Forces on single point cutting tool

In this experimental work the Feed and Radial forces are measured with a piezoelectric 3-Component Dynamometer (Kistler- 9257B) and charge amplifiers (Kistler Type 5814B1) available at National Small Industries Corporation L.T.D, Aligarh (U.P.) as shown in Fig.6

Fig. 6: Photograph of Kistler piezoelectric dynamometer and Kistler Charge amplifier

Surface roughness or surface finish is an important measure of product quality and performance. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. In this paper, Average Surface roughness is measured by direct contact method using Profilometer as shown in Fig.7

Fig 7: Photoghaph of Profilometer (SRT-6210).

3.3.1 SELECTION OF ORTHOGONAL ARRAYS AND EXPERIMENTAL DESIGN

The DOF is defined as the number of comparisons between machining parameters that need to be made to determine, which level is better and specifically how much better it is. As per Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (DOF) and OA (Orthogonal Array) to be selected must satisfy the following conditions:

D.O.F. of O.A. selected ≥ D.O.F. required.

The experiment under consideration has 6 D.O.F. and therefore requires an O.A with 8 or more D.O.F. Hence an O.A. with at least 9 experiments is to be selected to estimate the effect of each factor and the desired interaction (if any).

For such kind of situation Taguchi L9 orthogonal array is used as shown in Table 3.

Surface roughness ,Feed and radial forces are being a 'lower the better' type of machining quality characteristic, the S/N ratio for this type of quality characteristic is calculated by the following equation is given below [9]:

$$\textbf{S/N ratio} = -10 \log_{10} \{(Y1^2 + Y2^2 + \ldots + YN^2)/N\} \quad \text{------------------ equation (1)}$$

Where Y_1, Y2. . …., Y_N are the responses of the machining characteristic, for a trial condition repeated n times. The S/N ratios were computed using Eq. 1 for each of the 9 trials and the values are reported in Table 4 and Table 5.

Table 3: The basic Taguchi L_9 Orthogonal array

Sr.No.	Cutting speed (V) (m/min)	Feed Rate (f) (mm/rev)	Depth of cut (d) (mm.)
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

Table 4: Experimental Data Related and S/N values for Feed (F_t) and Radial Force (F_r).

S.No.	V	F	d	Feed force					Radial force				
				F_{t1}(N)	F_{t2} (N)	F_{t3} (N)	F_t (N)	S/N	F_{r1} (N)	F_{r2} (N)	F_{r3} (N)	F_r (N)	S/N
1.	100	0.05	0.4	49.75	52.88	49.34	50.66	-34.10	29.85	31.72	29.60	30.39	-29.66
2.	100	0.11	0.8	67.31	71.10	69.00	69.01	-36.80	40.38	42.66	41.40	41.41	-32.36
3.	100	0.17	1.2	84.39	83.85	86.22	84.82	-38.57	49.63	49.31	50.73	49.89	-33.96
4.	150	0.05	0.8	66.22	64.23	62.22	64.22	-36.16	39.73	38.54	37.33	38.53	-31.72
5.	150	0.11	1.2	76.65	77.13	78.21	77.33	-37.77	45.99	46.27	46.92	46.39	-33.33
6.	150	0.17	0.4	61.01	61.01	64.22	62.08	-35.86	35.60	35.61	37.53	36.25	-31.19
7.	200	0.05	1.2	69.22	69.11	69.02	69.12	-36.79	41.53	41.47	41.41	41.47	-32.35
8.	200	0.11	0.4	54.55	52.25	54.55	53.78	-34.61	32.73	31.35	32.73	32.27	-30.18
9.	200	0.17	0.8	68.47	67.39	67.93	67.93	-36.64	39.08	39.43	39.76	39.76	-31.92

Average Feed force height Y1 = 66.5 N, Average Radial force height Y2 = 39.60 N.

Table 5: Experimental Data & S/N values for R_a

S.No.	R_1 (μm)	R_2 (μm)	R_3 (μm)	R_a (μm)	S/N ratio
1	1.11	1.16	1.33	1.20	-1.61
2	2.21	2.44	2.76	2.47	-7.89
3	3.39	3.98	4.29	3.89	-11.83
4	1.52	1.42	1.63	1.52	-3.67
5	2.82	2.99	2.49	2.77	-8.86
6	2.39	2.56	2.41	2.45	-7.80
7	1.45	1.81	2.35	1.87	-5.60
8	1.80	1.66	1.87	1.78	-5.00
9	3.42	2.82	2.93	3.05	-9.74

Average surface roughness height Y3 = **2.33** μm.

4.ANALYSIS PROCEDURE AND DISCUSSION

The experiments are conducted to study the effect of process parameters over the output response characteristics and the experimental results for feed and radial forces are given in table 4, for surface roughness is given in table 5. For analyzing the results first calculate S/N ratio for all responses with Lower the better criterion by equation 1, given in table 4 and table 5 and analysis of S/N ratio are done with the help of Taguchi design of experiment using Minitab-16 software. The mean response refers to the average value of the performance characteristic for each parameter at different levels. The average values of responses and S/N ratios for each parameter at levels 1, 2 and

3 are calculated, plotted and tabulated in following Figures and Tables. It is clear from mean response, S/N ratio and ANOVA analysis that:

From fig. 8, feed force is minimum at the 3rd level of parameter V, 1st level of parameter f and 1st level of parameter d. By the table 7 the effect of machining parameters are shown that when the cutting speed is increased from 100 m / min to 200 m / min, feed force is decreased from 68.2 N to 63.61 N, when the feed rate is increased from 0.05 mm/rev to 0.17 mm/rev, feed force is increased from 61.33 N to 71.61 N, when the depth of cut is increased from 0.4 mm to 1.2 mm, feed force is increased from 55.51 N to 77.09 N. It is clear from ANOVA data table 8; the contributions of cutting speed, feed rate and depth of cut for feed force are 4.3%, 17.5%and77.29% respectively.

Table 6: Response Table for S/N Ratios of feed force.

Level	V	f	d
1	-36.49	**-35.68**	**-34.86**
2	-36.60	-36.39	-36.53
3	**-36.02**	-37.02	-37.71
Delta	0.58	1.34	2.85
Rank	3	2	1

Table 7: Response Table for Means of feed force.

Level	V	f	d
1	68.20	**61.33**	**55.51**
2	67.88	66.75	67.10
3	**63.61**	71.61	77.09
Delta	4.59	10.28	21.58
Rank	3	2	1

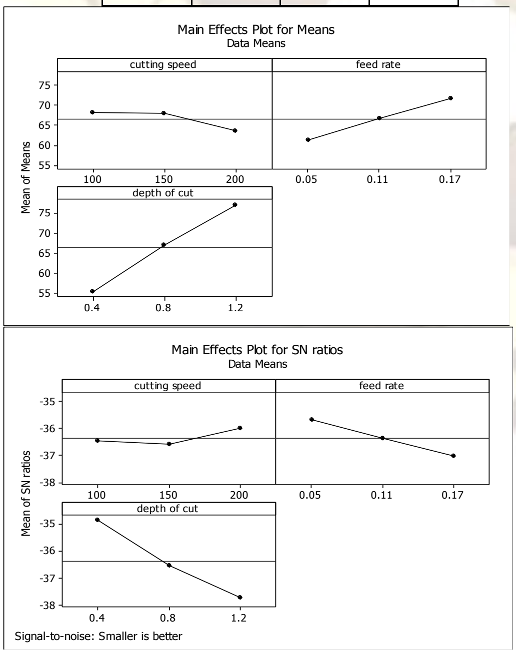


Fig 8: Feed force Main effects plot for S/N ratio and means

Table 8: ANOVA data table for feed force

Source	DOF	SS	MS	F ratio	Cont. %
V	2	39.02	19.51	4.82	4.3
f	2	158.5	79.26	19.59*	17.5
d	2	699.9	349.9	86.50*	77.3
Error	2	8.09	4.05		1
Total	8	905.5			

Tabulated F-ratio at 95% confidence level: F0.05; 2; 2 = 19

* Significant at 95% confidence level.

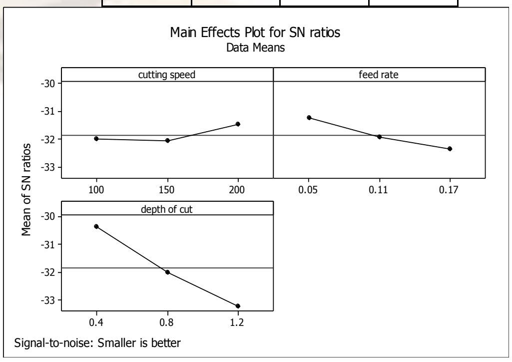
From fig. 9, radial force is minimum at the 3rd level of parameter V, 1st level of parameter f and 1st level of parameter d. By the table 10 the effect of machining parameters are shown that when the cutting speed is increased from 100 m / min to 200 m / min, radial force is decreased from 40.59 N to 37.72 N, when the feed rate is increased from 0.05 mm/rev to 0.17 mm/rev, radial force is increased from 36.80 N to 41.85 N, when the depth of cut is increased from 0.4 mm to 1.2 mm, radial force is increased from 32.97 N to 45.92 N. It is clear from ANOVA data table 11; the contributions of cutting speed, feed rate and depth of cut for radial force are 4.53%, 13.18% and 81.33% respectively.

Table 9: Response Table for S/N ratio of radial force.

Level	V	f	d
1	-31.99	**-31.24**	**-30.34**
2	-32.08	-31.96	-32.00
3	**-31.48**	-32.36	-33.22
Delta	0.60	1.11	2.87
Rank	3	2	1

Table 10: Response Table for Means of radial force.

Level	V	f	d
1	40.59	**36.80**	**32.97**
2	40.39	40.05	39.81
3	**37.72**	41.85	45.92
Delta	2.87	5.06	12.95
Rank	3	2	1



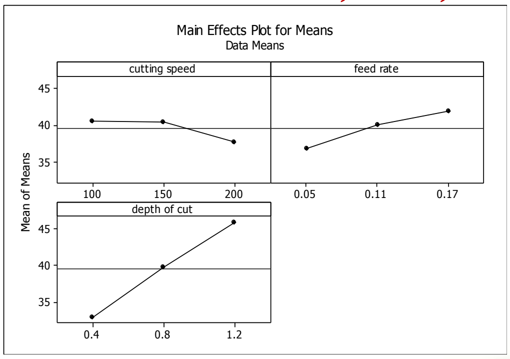


Fig 9: Radial force Main effects plot for S/N ratio and means

Table 11: ANOVA data table for radial force

Source	DOF	SS	MS	F ratio	Con. %
V	2	14.05	7.02	4.82	4.53
f	2	40.85	20.43	14.02	13.18
d	2	251.96	125.98	86.50*	81.33
Error	2	2.91	1.46		1
Total	8	309.78			

Tabulated F-ratio at 95% confidence level: F0.05; 2; 2 = 19

* Significant at 95% confidence level.

From fig. 10, surface roughness is minimum at the 3rd level of parameter V, 1st level of parameter f and 1st level of parameter d. By the Table 13 the effect of machining parameters are shown that when the cutting speed is increased from 100 m / min to 200 m / min, surface roughness is decreased from 2.519µm to 2.234µm, when the feed rate is increased from 0.05 mm/rev to 0.17 mm/rev, surface roughness is increased from 1.531µm to 3.132µm, when the depth of cut is increased from 0.4 mm to 1.2 mm, surface roughness is increased from 1.810µm to 2.841µm. It is clear from ANOVA data table 14 the contributions of cutting speed, feed rate and depth of cut for surface roughness are 2.8%,68.2%and26.5% respectively.

Table 12: Response Table for S/N Ratios of R_a

Level	V	f	d
1	-7.111	**-3.628**	**-4.804**
2	-6.777	-7.252	-7.099
3	**-6.781**	-9.789	-8.766
Delta	0.333	6.161	3.962
Rank	3	1	2

Table 13: Response Table for Means of R_a

Level	V	f	d
1	2.519	**1.531**	**1.810**
2	2.248	2.338	2.350
3	**2.234**	3.132	2.841
Delta	0.284	1.601	1.031
Rank	3	1	2

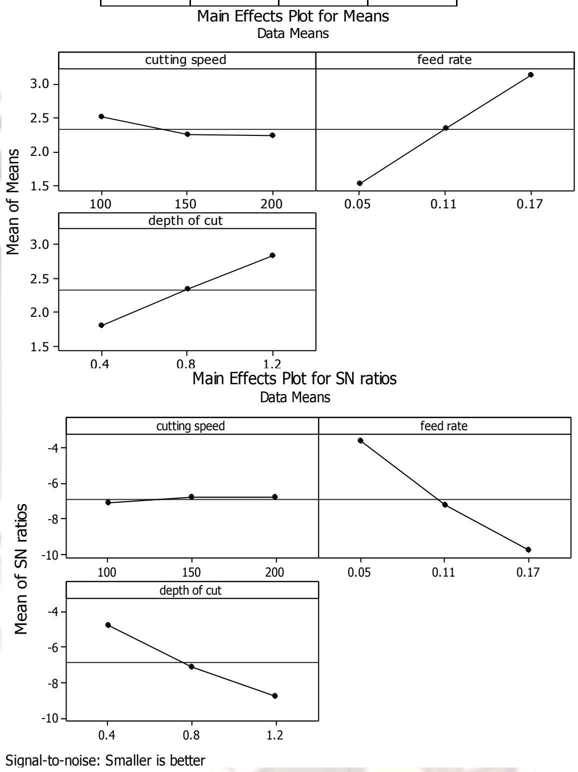


Fig 10: Surface Roughness Main effects plot for S/N ratio and means

Table 14: ANOVA data table for surface roughness

Source	DF	SS	MS	F ratio	Con. %
Cutting speed	2	0.16	0.0785	5.85	2.8
Feed rate	2	3.84	1.9201	142.94**	68.2
Depth of cut	2	1.50	0.8012	59.65*	26.5
Error	2	0.13	0.0134		3
Total	8	5.62			

Tabulated F-ratio at 95% confidence level: F0.05; 2; 2 = 19

* Significant at 95% confidence level.

4.1 PREDICTED RESULT (BY TAGUCHI METHOD):

The predicted values of Responses at the optimal levels are calculated by using the relation:

$$ñ = nm + \sum_{i=1}^{o}(nim - nm)$$

Where, **ñ** - Predicted response value after optimization, **nm** - Total mean value of quality characteristic, **nim** - Mean value of quality characteristic at optimal level of each parameter, **o** - Number of main machining parameters that affect the response parameter.

ñ F_t = 66.5+(63.61-66.5)+(61.33-66.5)+(55.51-66.5) = 47.45 N

ñ F_r = 39.6+(37.72-39.6)+(36.8-39.6)+(32.97-39.6) = 28.29 N

ñ R_a= 2.33+(2.234-2.33)+(1.531-2.33)+(1.810-2.33)

= 0.915 µm

5. DEVELOPMENT OF MATHEMATICAL REGRESSION MODELS

The experimental results are used to obtain the mathematical relationship between process parameters and machine outputs. The coefficient of mathematical models is computed using method of general linear regression. For calculate the linear regression equation minitab-16 software is used. The feed force (F_c), radial force and surface roughness are expressed as:

R_a = 0.263333 - 0.00286667 V + 13.3333 f + 1.29167 d

F_t = 42.3764 - 0.0455333 V + 85.6389 f + 26.9792 d

F_r = 26.0092 - 0.02732 V + 43.05 f + 16.1875 d

5.1 PREDICTED RESULT (BY REGRESSION MODEL):

R_a = 0.263333 - 0.00286667*200 + 13.3333 *0.05 + 1.29167 *0.4 =0.87333 µm

F_t = 42.3764 - 0.0455333 *200 + 85.6389 *0.05 + 26.9792 *0.4 = 48.34 N

F_r = 26.0092 - 0.02732 *200 + 43.05 *0.05 + 16.1875 *0.4 =29.17 N

6 CONFIRMATION & VALIDATION OF OPTIMAL SETTINGS

To validate the optimal cutting conditions suggested by Taguchi methodology the planning layout of the confirmation experiments verify improvement of the performance characteristic, while considering noise factors (variation of feed and radial forces during CNC turning process, variation of surface roughness at different locations); the total two confirmation experiments are conducted, measure feed and radial forces at different time intervals, surface roughness at different location have been taken and tabulated in Table 15,Table 16 and Table 17.

Table 15: Experimental results of feed force of final Confirmation Experiment.

Exp. No.	F_{t1}(N)	F_{t2}(N)	F_{t3}(N)	F_t(N)
1	46.25	48.55	48.70	47.83
2	49.25	48.22	50.12	49.19

Average value of feed force = 47.83+49.19=48.51 N

Table 16: Experimental results of radial force of final Confirmation Experiment.

Exp. No.	F_{r1}(N)	F_{r2}(N)	F_{r3}(N)	F_r(N)
1	29.05	27.35	28.35	28.25
2	28.56	29.95	31.04	29.85

Average value of radial force =28.25+29.85=29.05 N

Table 17: Experimental results of surface roughness of final Confirmation Experiment.

Exp. No.	R_1(µm)	R_2(µm)	R_3(µm)	R_a(µm)
1	1.05	1.20	1.23	1.16
2	0.98	1.06	1.08	1.04

Average value of surface roughness = 1.1 µm

7. COMPARISONS OF THE RESULTS

The outcome of the calculations and formulation for the optimization by the methods i.e. Prediction by Taguchi Method and Regression modeling. By using the optimal factor level combination suggested by Taguchi Methodology the experiments are conducted and the results are summarized in the table 18.

Table 18: Comparison of the Results of cutting performance using the initial & optimal cutting factors settings.

	Initial Cutting Parameters	Optimal Cutting Parameters		
		Prediction (Taguchi Method)	Prediction (Regression Modeling)	Experiment
Level Ft	V_1 f_1 d_1 50.66N	V_3 f_1 d_1 47.45 N	V_3 f_1 d_1 48.34 N	V_3 f_1 d_1 48.50 N
Level Fr	V_1 f_1 d_1 30.39N	V_3 f_1 d_1 28.29 N	V_3 f_1 d_1 29.1727 N	V_3 f_1 d_1 29.05 N
Level R_a	V_1 f_1 d_1 1.2 µm	V_3 f_1 d_1 0.915 µm	V_3 f_1 d_1 0.87333 µm	V_3 f_1 d_1 1.1 µm

Improvement in feed force = 50.66-48.50=2.16N

Improvement in radial force = 30.39-29.05=1.34 N

Improvement in surface roughness = 1.2 -1.1=0.1 µm

8. CONCLUSION

Experiments conducted according to Taguchi Parameter Design of Minitab-16 software and subsequently analysis performed by using the Taguchi Method and Regression Modeling. Optimal machining conditions are identified for CNC turning of EN-19 (ANSI 4140 medium carbon steel) material. The confirmation experiments are conducted then the results obtained are compared with the above said optimization methods are discussed as follows:

- Depth of Cut represents the largest influence on surface roughness, feed and radial forces followed by feed rate, and finally Cutting Speed.
- From ANOVA Table 8 and Table 14, it is apparent that the F- ratio values of Depth of cut and Feed rate are greater than $F_{0.05,\ 2,\ 2}$ =19.00. While Cutting Speed is proved to be a least significant machining factor for feed force and surface roughness.
- From ANOVA Table 11 it is apparent that the F-ratio values of Depth of cut greater than $F_{0.05,\ 2,\ 2}$ =19.00. While cutting speed and feed rate are proved to be a least significant machining factor for radial force.
- Final confirmation result shows that at optimal cutting parameters feed force is reduced from 50.66N to 48.50 N, radial force is reduced from 30.39N to 29.05 N, surface roughness is reduced from 1.2 µm to 1.1 µm.
- This paper has discussed an application of the Taguchi parameter design method for optimizing surface roughness, feed and radial forces in turning operation and indicated that the Taguchi parameter design of experiment is an effective way of determining the optimal cutting factors for obtaining optimum value of responses with a relatively small number of experimental runs.

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