RESEARCH ARTICLE OPEN ACCESS

Optimizing Feed and Radial Forces on Conventional Lathe Machine of En31b Alloy Steel through Taguchi's Parameter Design Approach

Mohd. Rafeeq[1], Mudasir M Kirmani[2]
[1]Assistant Professor (Mechanical Engineering), Maulana Azad National Urdu University, Hyderabad, A.P., India.
[2]Assistant Professor (computer Science), SKUAST-K, Srinagar, J&K, India.

Abstract
The present paper outlines an experimental study to obtain an optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal values of the feed force and radial force when machining EN31B steel with TiC-coated tungsten carbide inserts. The effects of cutting parameters on the feed and radial force were experimentally investigated. Experimentation was conducted as per Taguchi's orthogonal array. Three cutting parameters with three levels are arranged in L_9 orthogonal array. The orthogonal array, measured values of feed and radial force, signal-to-noise ratios, and analysis of variance are employed in order to study the feed force and radial force. The analysis of the results shows that the optimal settings for low values of feed and radial forces are high cutting speed, low feed rate and depth of cut.
Keywords. Cutting parameters; turning process; feed force; radial force Taguchi technique; EN31B steel; coated carbide inserts.

I. INTRODUCTION

In today's rapidly changing scenario in manufacturing industries, applications of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market.

Turning is the most widely used among all cutting processes. 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 manufacturing of machined parts .Researchers have focused on improving the performance of turning operation with the aim of minimizing time, costs and improving quality of manufactured products. Machinability of materials in turning is studied usually in terms of feed and radial forces, cutting temperature, surface quality and tool wear. Forces play a major role in the machinability evaluation of the material. A lower feed and radial force is always preferred for long tool life, lower deflection, lesser power consumption and improved surface finish. Finding process parameters that optimize feed and radial force is an important task towards enhancing efficiency of machining process.

This study helpful in evaluating optimum machining parameter like tool geometry, tool material, cutting speed, feed and depth of cut for forces for turning EN31B steel on kirloskar Lathe machine. Taguchi's parameter optimization method is used to evaluate best possible combination for minimum cutting force during machinability. The literature survey reveals that the machining of difficult-to-machine materials like EN31B is relatively a less researched area. The objective of this case study is to obtain optimal settings of turning process parameters –cutting speed, feed rate and depth of cut, to yield optimal feed and radial forces while machining EN31B steel with TiC-coated carbide tools. Taguchi's parameter design approach has been used to accomplish this objective.

II. TAGUCHI METHOD

Taguchi method of design of experiment [1, 2] is a relatively simple and powerful tool for systematic modelling, analysis and optimization of the machining process. Taguchi method includes selection of parameters, experimental design, conducting an experiment, data analysis, determining the optimal combination, and verification. Noorul and Jeyapaul [3] adopted orthogonal array, Grey relational analysis in the ANOVA using Taguchi method to find suitable level of identified parameters, and significant association of parameters in order to increase multiple response efficiency of parameters in driller operation for Al/SiC.

By this method the product quality is defined in terms of loss function (S/N ratio), due to deviation of the product's functional characteristics from its desired target value. Taguchi method uses a special design of orthogonal arrays (OA), where the experimental results are transformed into signal-to-noise (S/N) ratio as the measure of the quality characteristic. An OA is a small fraction of full factorial design and assures a balanced comparison of levels of any parameter or interaction of parameters. The columns of an OA represent the experimental parameters to be optimized and the rows represent the individual trials (combinations of levels). Traditionally, data from experiments are used to analyze the mean response. Taguchi method estimates the effects of factors on the response mean and variation. In Taguchi method the mean and the variance of the response (experimental result) at each parameter setting in OA are combined into a single performance measure known as the signal-to-noise (S/N) ratio. Taguchi method utilizes the S/N ratio approach to measure the quality characteristic deviating from the desired value. The S/N ratio is a quality indicator by which the experimenters can evaluate the effect of changing a particular experimental parameter on the performance of the process. Depending on the criterion for the quality characteristic to be optimized, the S/N ratio characteristics can be divided into three stages: smaller-the-better, larger-the-better, and nominal-the-better. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the parameter is the level with the highest S/N ratio. The optimal parameter levels are determined using the analysis of means and analysis of variance (ANOVA). A confirmation experiment is the final step in Taguchi method and it is used to verify the optimal combination of the parameter settings.

There are some studies regarding optimization of cutting parameters based on cutting force in turning operation using Taguchi method. Singh & Kumar [1] have applied Taguchi method for optimization of cutting parameters based on cutting force in a longitudinal turning of an alloy steel EN24. Controlled factors are cutting speed, feed and depth of cut with three levels. Response factor is main cutting force. They applied L_{27} orthogonal array with interactions. Petropoulos et al. [2] have applied Taguchi method for optimization of cutting parameters based on cutting force in a longitudinal turning of carbon steel St37. Controlled factors are spindle speed, feed and depth of cut with four levels. Response factors are main cutting force, feed force and passive force. They applied L_{16} orthogonal array with interactions. In another paper, Singh & Kumar [4] have applied Taguchi method in order to optimize cutting parameters based on cutting force in a longitudinal turning of an alloy steel EN24. One can consider that the controlled factors are cutting speed, feed and depth of cut with three levels. Response factor is feed force. They applied L_{27} orthogonal array, by taking into consideration the interactions. Aggarwal et al. [5] have applied Taguchi method for optimization of cutting parameters based on cutting force in a longitudinal turning of tool steel P20. Controlled factors are cutting speed, feed, depth of cut, nose radius and cutting environment with three levels. Response factors are feed force and passive force. They applied L_{27} orthogonal array with interactions. Hanafi et al. [6] have applied Taguchi method for optimization of cutting parameters based on cutting force and surface roughness in a longitudinal turning of carbon fiber PEEK CF30. Controlled factors are cutting speed, feed and depth of cut with three levels. Response factors are main cutting force and surface roughness. They applied L_{27} orthogonal array with interactions.

2.1 TAGUCHI EXPERIMENT: DESIGN AND ANALYSIS

Essentially, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [7].

Taguchi methods [8] have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly. Taguchi's robust design method is a powerful tool for the design of a high-quality system. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on metal removal rate values. In general, the parameter optimization process of the Taguchi method is based on 8-steps of planning, conducting and evaluating results of matrix experiments to determine the best levels of control parameters [9]. Those eight steps are given as follows.

- Identify the performance characteristics (responses) to optimize and process parameters to control (test).
- Determine the number of levels for each of the tested parameters.
- Select an appropriate orthogonal array, and assign each tested parameters into the array.

- Conduct an experiment randomly based on the arrangement of the orthogonal array.
- Calculate the S/N ratio for each combination of the tested parameters.
- Analysis the experimental result using the S/N ratio and ANOVA test.
- Find the optimal level for each of the process parameters.
- Conduct the confirmation experiment to verify the optimal process parameters.

III. EXPERIMENTAL SET-UP AND PROCESS PARAMETER SELECTION

3.1 Work piece material

The work piece material selected for investigation was EN31B alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear and finds its applications in the manufacturing of punches and dies. EN31B alloy steel is density: 7.81 g cm^{-1}, Hardness: 58 to 62 HRC, Modulus of Elasticity: 210GPa and Shear Modulus: 80GPa. The chemical composition of work piece material is given in Table 1.

Table 1. Chemical Composition of Work Piece Material

Constituent	C	Mn	Si	P	Cr	S
% composition	0.98	0.25	0.15	0.025	1.3	0.025

3.2 Turning process parameters

To identity the process parameters affecting the selected machining quality characteristic of turned parts. An Ishikawa cause –effect diagram was constructed and shown in Fig 1.The identified process parameters were the cutting tool parameters – tool geometry, tool material, the cutting parameters – spindle speed, feed rate, depth of cut, work piece-related parameters – hot-worked, difficult-to-machine.

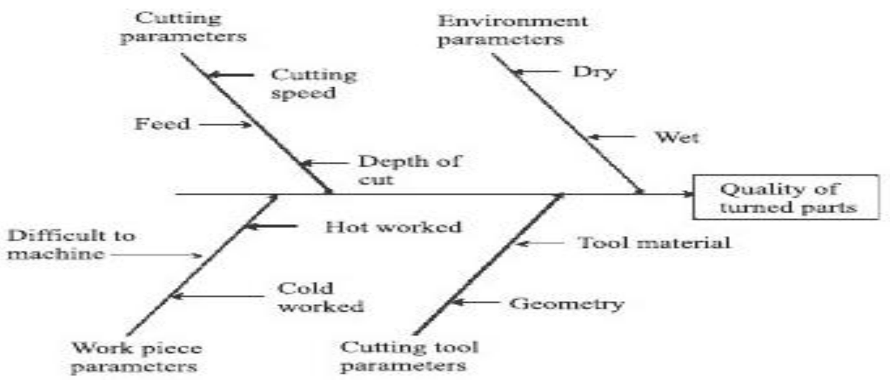


Fig 1: Ishikawa cause –effect diagram

The following process parameters were thus selected for the present work: Cutting speed –(A), feed rate – (B), depth of cut – (C), tool material – TiN coated tungsten carbide inserts of Widia make, the tungsten carbide inserts used were of ISO coding CNMG 120404 and tool holder of ISO coding PCLNR 1616H07 , work material –EN31B steel, and environment – dry cutting.

3.3 Plan of Experiment

Taghuchi methods which combine the experiment design theory and quality loss function concept have been used in developing robust design of product and process and in solving more taxing of manufacturing[10] .the degree of freedom of three parameter in each of three levels are calculated as follows [11].

Degree of freedom (DOF) = number of levels -1
For each factor.DOF equal to;
For (A); DOF=3-1=2
For (B); DOF=3-1=2
For (C); DOF=3-1=2

In this paper nine experiments were conducted at different parameter. For this Taghuchi L_9 orthogonal array was used, which has nine rows corresponding to the number of tests, with three columns at three levels. L_9 orthogonal array has 8 DOF, in which 6 were assigned to three factors (each one 2 DOF) and 2 DOF was assigned to the error. For the purpose of observing the degree of influence of the parameter in machining three parameter at all three levels are taken into account. The cutting parameter identified were spindle speed, feed rate and depth of cut. The controls parameter and their level is indicated in Table 2.

Table 2. Process parameters with their values at 3 levels

Parameter	Process parameters	Level 1	Level 2	Level 3
A	Spindle speed(RPM)	224	500	775
B	Feed rate (mm/rev)	0.12	0.15	0.18
C	Depth of cut (mm)	1	1.25	1.5

Table 3. Orthogonal Array L_9 of Taguchi

Experiment. no.	Spindle speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)
1	224	0.12	1
2	224	1.15	1.25
3	224	0.18	1.50
4	500	0.12	1.25
5	500	0.15	1.50
6	500	0.18	1.00
7	775	0.12	1.50
8	775	0.15	1.00
9	775	0.18	1.25

3.4 Experiment set-up

EN321B steel rods (40 mm diameter and 250 mm length) turned on kirloskar lathe. Titanium carbide – coated inserts is used to machine the work material EN31B .Specimens is turned for each trial condition given in Table-3. Using random technique, nine experiments is thus turned and feed force and radial force is measured with a three dimensional turning dynamomter.The dynamometer capable of taking reading in kgf units. The readings have been converted into Newton in Table 4. A photograph of experimental set –up is shown in Fig 2.

Fig 2.

A pictorial view of experimental set –up

Table 4. Experiment Data of Feed Force and Radial Force

Trail no.	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Feed force (N)	Radial force (N)
1	224	0.12	1.00	49.05	29.43
2	224	0.15	1.25	78.48	49.05
3	224	0.18	1.50	98.10	78.48
4	500	0.12	1.25	58.86	29.43
5	500	0.15	1.50	88.29	68.67
6	500	0.18	1.00	68.67	39.24
7	774	0.12	1.50	88.29	68.67
8	774	0.15	1.00	68.67	39.24
9	774	0.18	1.25	78.48	49.05
Total				676.89	451.26

$\overline{T}_{FF}$ = Overall mean of feed force = 75.21 N $\overline{T}_{RF}$ = Overall mean of radial force = 50.14N

IV. RESULTS AND ANALYSIS OF EXPERIMENTS

4 .1 Analysis of the signal to noise (S/N) ratio

In the Taguchi approach, the term signal represents the desired value (mean) for the output characteristics and term noise represents the undesirable value (standard deviation) for the output characteristics. Taguchi uses the S/N ratio to measure the quality characteristics deriving from desired value .There are several S/N ratio available depending upon of characteristic: lower is better, smaller is better or higher is better. The experimental data for the feed and radial forces have been reported in Table 5. Feed and radial forces being 'smaller is better' a type of machining Quality characteristic, the S/N ratio for these types of response was used and is given below. [12]

$$S/N = -10\log\left[\frac{1}{n}(y_1^2 + y_2^2 + \ldots\ldots + y_n^2)\right] \ldots\ldots\ldots (1)$$

where $y_1, y_2, \ldots y_n$ are responses of the machining characteristic for a trail condition repeated n times. The S/N ratios were computed using equation (1) for each of the nine trail and the results are reported in Table 5 along with the raw data value.

Table 5. Experimental Results of Feed Force and Radial Force

Factors				Feed force (N)	S/N ratio (db)	Radial force (N)	S/N ratio (db)
Trail no.	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)				
1	224	0.12	1.00	49.05	-33.81	29.43	29.37
2	224	0.15	1.25	78.48	-37.89	49.05	33.81
3	224	0.18	1.50	98.10	-39.83	78.48	37.89
4	500	0.12	1.25	58.86	-35.39	29.43	29.37
5	500	0.15	1.50	88.29	-38.91	68.67	36.73
6	500	0.18	1.00	68.67	-36.73	39.24	31.91
7	774	0.12	1.50	88.29	-38.91	68.67	36.73
8	774	0.15	1.00	68.67	-36.73	39.24	31.73
9	774	0.18	1.25	78.48	-37.89	49.05	33.81

The mean response refers to the average value of each performance characteristic for each parameter at level 1, 2 and 3 are calculated and are given in Table 6 and 7. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. The effects of process parameters on feed force are given in Fig-1 while as effects of process parameters on radial force are given in Fig-4.

TABLE 6. AVERAGE VALUES (RAW DATA: FEED FORCE)

Process parameter Designation	Average values of feed force(N)			Delta	Rank
	L1	L2	L3		
A	75.21	71.64	78.54	6.53	3
B	64.40	78.48	81.75	16.36	2
C	62.13	71.94	91.56	29.42	1

TABLE 7. AVERAGE VALUES (RAW DATA: RADIAL FORCE)

Process parameter Designation	Average values of feed force(N)			Delta	Rank
	L1	L2	L3		
A	52.32	45.32	52.30	6.54	3
B	42.49	52.32	55.59	13.10	2
C	35.97	42.51	71.90	35.42	1

Fig 3. Effects of Process Parameters on feed force (Raw Data)

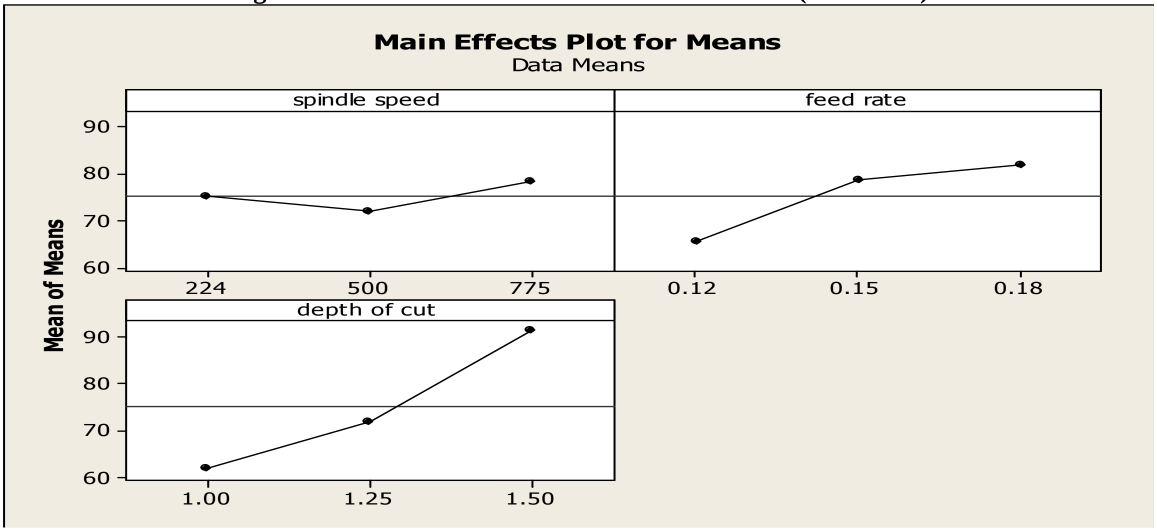
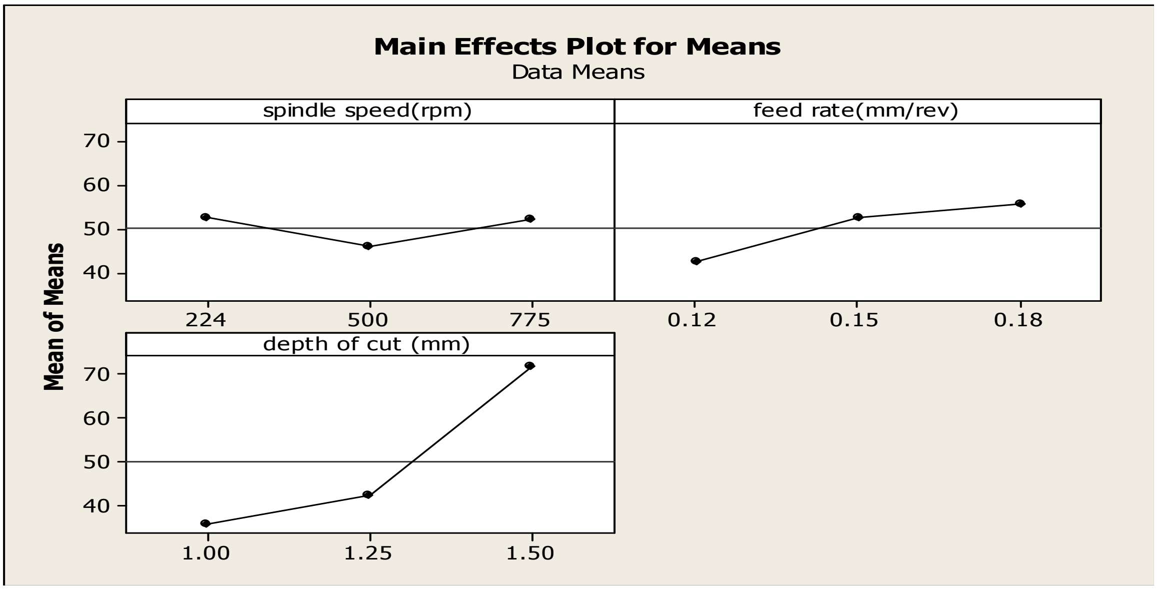


Fig 4. Effects of Process Parameters on radial force (Raw Data)



The average value S/N ratio of various parameters at different levels are calculated and shown in Table 8 and 9. The level of a factor with the highest S/N ratio is the optimum level for responses measured.

TABLE 8. S/N RATIO AVERAGE VALUES (RAW DATA: FEED FORCE)

Process parameter Designation	Average values of feed force(N)			Delta	Rank
	L1	L2	L3		
A	-37.17	-37.01	-37.84	0.83	3
B	-36.04	-37.84	-38.15	2.11	2
C	-35.76	-37.61	-39.22	3.46	1

TABLE 9. S/N RATIO AVERAGE VALUES (RAW DATA: RADIAL FORCE)

Process parameter Designation	Average values of feed force(N)			Delta	Rank
	L1	L2	L3		
A	-33.69	-32.67	-34.09	1.48	3
B	-31.82	-34.09	-34.55	2.70	2
C	-31.00	-32.33	-37.12	6.08	1

The average value S/N ratio of Effects of Process Parameters on Feed Force (S/N Data) is shown in Fig-5 and the Effects of Process Parameters on radial force (S/N Data) is shown in Fig-6.

Fig 5. Effects of Process Parameters on Feed Force (S/N Data)

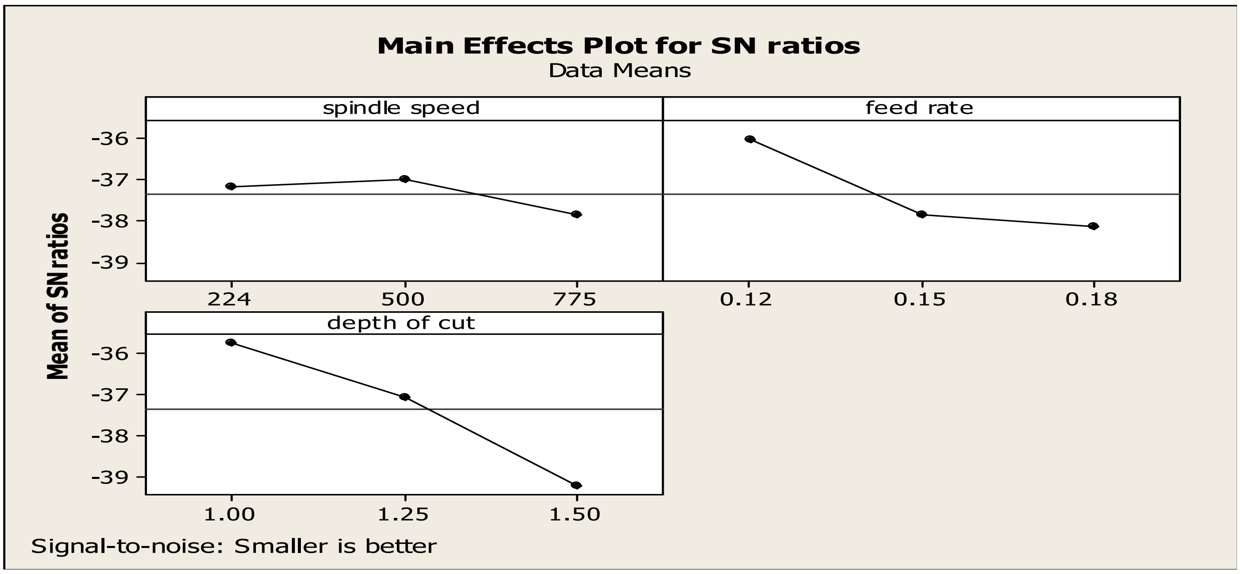
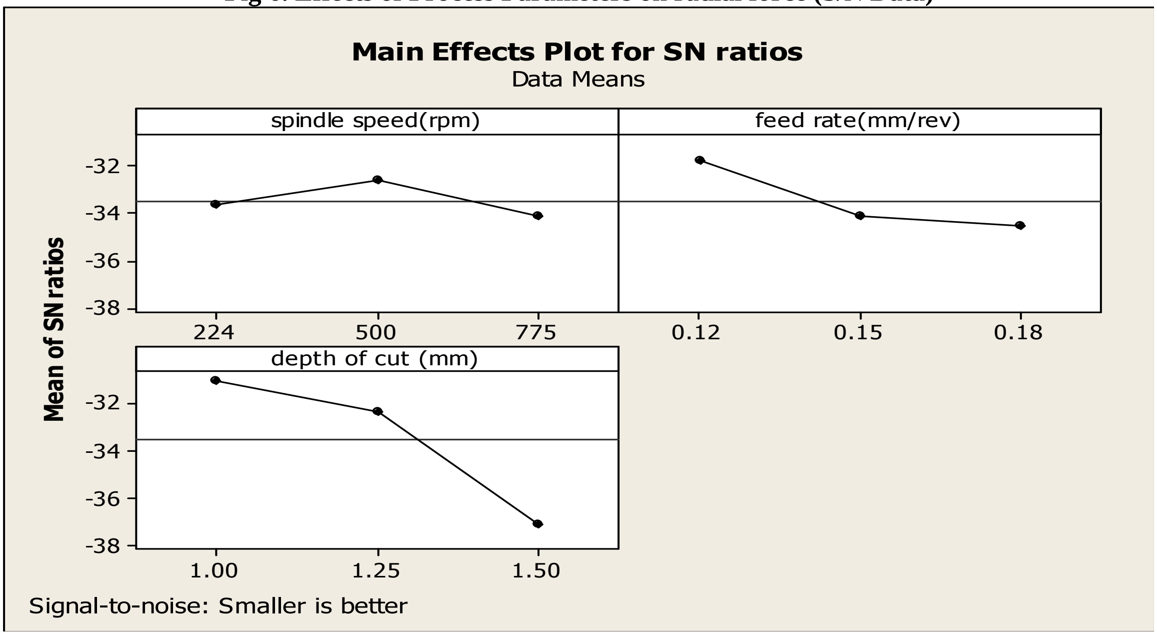


Fig 6. Effects of Process Parameters on radial force (S/N Data)



From the S/N ratio analysis in Fig. 5-6, the optimal machining conditions are 500 rpm spindle speed (level 2), 0.12 mm/rev feed rate (level 1) and 1mm depth of cut (level 1) for feed force and 500 rpm spindle speed (level 2), 0.12 mm/rev feed rate (level 1) and 1mm depth of cut (level 1) for radial force, respectively.

4.2 Analysis of Variance (ANOVA)

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. First, the total sum of squared deviations SS_T from the total mean S/N ratio n_m can be calculated as [13]:

$$SS_T = \sum_{i=1}^{n} (n_i - n_m).^2 \ldots\ldots\ldots (2)$$

where n is the number of experiments in the orthogonal array and n_i is the mean S/N ratio for the i^{th} experiment.

$$P = \frac{SS_d}{SS_T} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Statistically, there is a tool called an F-test, named after Fisher [14], to see which design parameters have a significant effect on the quality characteristic. In the analysis, the F-ratio is a ratio of the mean square error to the residual error, and is traditionally used to determine the significance of a factor. The contribution of parameter for feed forces is shown in Table 10 and11.

TABLE 10. ANOVA RESULTS (RAW DATA: FEED FORCE)

Source	Degree of freedom	Sum of squares	variance	F-ratio	Percentage
A	2	63.90	31.95	1.00	3.321
B	2	449.89	224.94	7.04	23.38
C	2	1346.0	673.00	21.07	69.97
Error	2	63.90	31.95		3.32
Total	8	1923.68			100

Tabulated F-ratio at 95% confidence level :F(0.05; 2;2) =19.0000
*Significant at 95% confidence interval

TABLE 11. S/N ANOVA RESULTS (RAW DATA: FEED FORCE)

Source	Degree of freedom	Sum of squares	variance	F-ratio	Percentage
A	2	1.1644	0.5822	0.82	4.049
B	2	7.8302	3.9151	5.50	27.23
C	2	18.3345	9.37115	12.58	63.76
Error	2	1.4229	0.7115		4.948
Total	8	28.7520			100

Tabulated F-ratio at 95% confidence Level: F (0.05; 2;2) =19.0000
*Significant at 95% confidence interval

It reveals that the influence of depth of cut in affecting the feed force is significantly larger followed by that of feed rate, spindle speed has little influence on feed force on feed force. The contribution of parameter for radial force as shown in Table 12 and 13.The results are similar to feed rate.

TABLE 12. ANOVA RESULTS (RAW DATA: RADIAL FORCE)

Source	Degree of freedom	Sum of squares	variance	F-ratio	Percentage
A	2	85.33	42.66	4.03	3.299
B	2	278.78	139.39	13.17	10.78
C	2	2200.56	1100.28	103.96	85.10
Error	2	21.17	10.25		0.818
Total	8	25585.83			100

Tabulated F-ratio at 95% confidence Level: F(0.05; 2;2) =19.0000
*Significant at 95% confidence interval

TABLE 13. S /N ANOVA RESULTS (RAW DATA: RADIAL FORCE)

Source	Degree of freedom	Sum of squares	variance	F-ratio	Percentage
A	2	3.445	1.722	1.77	4.321
B	2	12.79	6.399	6.58	16.05
C	2	61.52	30.76	31.61	77.18
Error	2	1.946	0.973		2.441
Total	8	79.709			100

Tabulated F-ratio at 95% confidence level:F(0.05; 2;2) =19.0000
*Significant at 95% confidence interval

V. ESTIMATION OF OPTIMUM RESPONSE CHARATERISTICS

Two factors (feed rate and depth of cut) are found significant in both raw data and S/N data analysis for the selected machining characteristic .Lowest levels of feed rate and depth of cut are the most desired conditions for both feed and radial force is considered.

The estimated mean of the response characteristic can be computed as [14].

$$\mu_{FF}=\overline{B}_1+\overline{C}_1-\overline{T}_{FF} \quad \ldots\ldots (4)$$

Where,

$\overline{B}_1$= average value of feed force e at the first level of feed rate = 64.40 N

$\overline{C}_1$ = average value of feed force at the third level of depth of cut = 62.13N

$\overline{T}_{FF}$ =overall mean of feed force =75.21 N

Substituting the values of various terms in the above equation,

μ_{FF} = 64.40 + 62.13 – 75.51 = 51.32N

The 95 % confidence interval for predicted mean on a confirmation run can be calculated by using the following equations [14].

$$C.I = \sqrt{F_\alpha(1,f_e)V_e\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]} \quad \ldots\ldots\ldots(5)$$

where, Fα (1, *f*e) = The F ratio required for α , α = risk , *f*e =error DOF, Ve =error variance ,

n_{eff}= effective number of replications

$$n_{eff}=\frac{N}{1+[\text{Total DOF associated in the estimate of mean}]}$$

R = Sample size for confirmation experiments, N = Total number of experiment.

Using the values Ve=31.95, *f*e =2 from (Table 10), the confidence interval was calculated.

Total DOF associated with the mean (n_{eff}) =2+2 =4, N=9

= 9 / (1 + 4) = 1.8, α=0.05,

$F_{0.05;(1,2)}$=18.51(Tabulated F value)

The calculated CI_{CE} is: CI = ± 22.91.

The predicted mean of feed force is: μ_{FF} = 51.32N

The 95% confidence interval of the predicted feed force is $[\mu_{FF} - CI] < \mu_{FF} < [\mu_{FF} + CI]$ i.e. $28.41< \mu_{FF} < 74.23$

Similar calculation done for radial force results in $\mu_{RF}=\overline{B}_1+\overline{C}_1-\overline{T}_{RF}$

The predicted mean of feed force is: μ_{RF} = 28.32N

$$C.I = \sqrt{F_\alpha(1,f_e)V_e\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]} \quad \pm 13.18$$

The 95% confidence interval of the predicted radial force is $[\mu_{RF} - CI] < \mu_{RF} < [\mu_{RF} + CI]$ i.e. $15.22< \mu_{RF} < 41.42$

VI. CONFIRMATION EXPERIMENT

In order to validate the results obtained, three confirmation experiments were conducted of the response characteristics (feed and radial force) at optimal levels of the process variables. The confirmation experiment is a crucial step and is highly recommended by taguchi to verify the experimental conclusion [14].

The average values of the characteristics were obtained and compared with the predicted values. The values of feed force and radial force obtained through confirmation experiments are within the 95% of CI of respective response characteristic. Three confirmation experiments were thus conducted at the optimal settings of the turning process parameters recommended by the investigation. The average value of feed force 44.78 N and that for radial force as 26.16 N while turning EN31B steel with TiN coated carbide inserts.

VII. CONCLUSIONS

The following conclusions can be drawn from this study:

- Statistically designed experiments based on Taguchi methods were performed using L_9 orthogonal arrays to analyze forces as response variable. Conceptual S/N ratio and ANOVA approaches for data analysis drew similar conclusions.
- Statistical results(at a 95% confidence level) shows that the depth of cut, and feed rate in affecting the variation of feed and radial forces are significantly larger as compared to the contribution of spindle speed.
- The optimal settings of various process parameters for machined parts to yield optimal feed force are: spindle speed =500rpm(A2) ; feed rate = 0.12 mm/rev (B1); depth of cut =1mm (C1).Optimal radial force is obtained at same levels of parameters.
- The predicted of optimal feed force and radial force are 28.41< μ_{FF} (N) < 74.23 and 15.22< μ_{RF} (N)< 41.42.

REFRENCES

[1] Singh, H., Kumar, P., Optimizing cutting force for turned parts by Taguchi's parameter design approach, Indian Journal of Engineering & Materials Sciences, Vol. 12, 97-103, (2005).

[2] Petropoulos, G., Ntziantzias, I., Anghel, C., A predictive model of cutting force in turning using Taguchi and Response surface techniques, 1st International Conference on Experiments / Process / System Modelling / Simulation/ Optimization – IC-EpsMsO, Athens, Greece, (2005).

[3] Noorul H.A., Marimuthu P. and Jeyapaul R., 2007.Multi response optimization of machining parameters of drilling Al/Sic metal matrix composite using grey relational analysis in the Taguchi method. Int.J Adv Manuf Technol: 250-255.

[4] Singh, H., Kumar, P., Optimizing feed force for turned parts through the Taguchi technique, Sadhana, Vol. 31 (6), 671-681, (2006).

[5] Aggarwal, A., Singh, H., Kumar, P., Singh, M., Optimizing feed and radial forces in CNC machining of P- 20 tool steel through Taguchi's parameter design approach, Indian Journal of Engineering & Materials Sciences, Vol. 16, , 23-32, (2009).

[6] Hanafi, I., Khamlichi, A., Mata Cabrera, F., Almansa, E., Jabbouri A., Optimization of cutting parameters in CNC turning operation using Taguchi design of experiments, Int. Rev. Appl. Sci. Eng. 2, 79-87, (2011).

[7] Yang WH, Tarng YS, Design optimization of cutting parameters for turning operations based on the Taguchi method, Journal of Material Processing Technology, 84, 1998, 122–129.

[8] Taguchi G, Introduction to quality engineering, (Asian Productivity Organization, Tokyo, 1990).

[9] T.R. Lin. Experimental design and performance analysis of TiN-coated carbide tool in face milling stainless steel, journal of Materials processing Technology 127 (2002), pp. 1-7.

[10] Tsao CC, Hocheng H, Taguchi analysis of delamination associated with various drill bits in drilling of composite material, International Journal of Machine Tools Manufacturing 44, 2004, 1085–1090.

[11] Taguchi G, Hocheng, Taguchi methods orthogonal arrays and linear graphs, tools for quality engineering, (Dearborn, MI: American Supplier Institute, 1987, 35 – 38).

[12] Roy R K, A Premier on Taguchi method (Van Noshtrand Reinhold Int.Co.Ltd, New York), 1990.

[13] Lindman H, Analysis of variance in experimental design, (Springer-Verlag, New York, 1992).

[14] Ross P J, Taguchi techniques for quality engineering, (McGraw-Hill Book Company, New York, 1996).

[15] Park S H, Robust design and analysis for quality engineering (Chapman and Gall, London), 1996.

[16] Phadke M S, Quality engineering using robust design (prentice Hall, R Englewood Cliffs, NJ), 1989.

[17] Montgomery D C, Design and analysis of experiments (John, Wiley &Sons, New York), 1997.

[18] P.J.Ross .2005.Taghuchi Techniques for Quality Engineering .2nd Edition .Tata McGraw Hill.

[19] Nalbant M. et al., 2007. Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Materials and Design. 28: 1379-1385.

[20] Thamizhmanil S., Saparudin S. and Hasan S., 2007. Analyses of surface roughness by turning process using Taguchi method. Journal of Achievements in Materials and Manufacturing Engineering. 20: 503-505.

[21] Aman Aggarwala , Hari Singh, Pradeep Kumar, Manmohan Singh, Optimizing power consumption for CNC turned parts

using response surface methodology and Taguchi's technique—A comparative analysis, journal of materials processing technology 200 (2008) 373–384.

[22] H. K. Dave, L. S. Patel and H. K. Raval ,Effect of machining conditions on MRR and surface roughness during CNC Turning of different Materials Using TiN Coated Cutting Tools – A Taguchi approach., International Journal of Industrial Engineering Computations 3 (2012).

[23] Kazancoglu, Y., Esme, U., Bayramoglu, M., Guven, O., Ozgun S., Multi-objective optimization of the cutting forces in turning operations using the Grey-based Taguchi method, Materials and Technology 45 2, 105-110, (2011).

[24] Kamal Hassan, Anish Kumar, M.P.Garg, Experimental investigation of Material removal rate in CNC turning using Taguchi method, International Journal of Engineering Research and Applications (IJERA) 2,2012, 1581-1590.

[25] Unal R & Dean E B, Taghuchi approach to design optimization for quality and cost :An Overview ,Proc 13th Annual Int Soc of parametric Analyst ,1991.