Optimization of CNC Turning Process Parameters for Prediction of Surface Roughness by Taguchi Orthogonal Array

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Abstract

In this study, the effects of cutting speed, feed rate, depth of cut, nose radius and cutting condition on surface roughness and vibration chatter in the turning were experimentally investigated. EN 24 steel was machined using carbide tool on CNC lathe machine. The settings of turning parameters were determined by using Taguchi's experimental design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA) are employed to find the optimal levels and to analyze the effect of the turning parameters. Results show that Nose Radius and the Cutting Speed and cutting condition are the three Parameters that influence the Surface Roughness more effectively. Finally, the ranges for best cutting conditions are proposed for serial industrial production.

***Keywords**:-* CNC Turning, Taguchi Orthogonal Array, Surface Roughness,ANOVA

1. Introduction

Today's fast changing manufacturing environment requires the application of optimization techniques in metal cutting processes to effectively respond to severe competitiveness and to meet the increasing demand of customizable quality product (low cost, high quality, easily deliverable) in the market[3].Machining vibration is important in metal cutting operations which may affect the quality characteristics. The machine tool operators always face the problem of chatter in turning process. Machine tool condition, job clamping, tool and workpiece geometry and cutting parameters are the major reasons for occurrence of this problem. Chatter vibration has been researched for more than a century and it is still a major obstacle in achieving automation for most of the machining processes including turning, milling and drilling. [1]. Vibration in machine tool is directly affecting the surface finish of the work material in turning process. So vibration of a machine tool is one of the major factors limiting its performance [2]. In machining, there has been recently and intensive computation focusing on surface roughness at international level. This computation can be observed in turning processes especially in plane and automotive industry by increasing the alternative solutions for obtaining more proper surface roughness [4]. So it becomes important to study the effect of machining parameters on multiple quality characteristics like surface roughness and vibration etc.

2. Literature review

Ballal Yuvaraj et al [3] This paper states, the Taguchi method to find a specific range and combinations of turning parameters like cutting speed , feed rate and depth of cut to achieve optimal values of response variables like surface finish, tool wear, material removal rate in turning of Brake drum of FG 260 gray cast iron Material. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities. Araştırma Makalesi et al [5] In this paper the effect of turning parameters such as cutting speed, feed rate and depth of cut on machining characteristics of AISI 304 steel was investigated. The highewqst tool – chip interface temperature was measured 356 °C at 100 m/min cutting speed, 0.2 mm/rev and 2mm depth of cut conditions. The most effective parameter on the temperature rise was found depth of cut. The surface roughness increased when the depth of cut and feed rate were increased while the cutting speed have an inverse influence. E. Daniel Kirby [6] This paper states that the use of a modified L8 orthogonal array, with three control parameters and one noise factor, required only sixteen work pieces to conduct the experimental portion, half the number required for a full factorial design. Feed rate had the highest effect on surface roughness, spindle speed had a moderate effect, and depth of cut had an insignificant effect. This would indicate that feed rate and spindle speed might be included alone in future studies, although the literature review would caution against ruling out depth of cut altogether. Kamal Hassan et al [7], this paper states that ,there is a number of parameters like cutting speed, feed and depth of cut etc. which must be given consideration during the machining of medium Brass alloy. This study investigates the effects of process parameters on Material Removal Rate (MRR) in turning of C34000. The single response optimization problems i.e. optimization of MRR is solved by using Taguchi method. The optimization of MRR is done using twenty seven experimental runs based on L'27 orthogonal array of the Taguchi method are performed to derive objective functions to be optimized within the experimental domain When the MRR is optimized alone the MRR comes out to be 8.91um. The Material removal rate is mainly affected by cutting speed and feed rate. With the increase in cutting speed the material removal rate is increases & as the feed rate increases the material removal rate is increase. From the above literature review it is seen that there is possibility to study the effect on different cutting parameters on the multiple responses and for that the use of Taguchi technique is suitable.

3. Taguchi based Design of experiments:

Among the available methods, Taguchi design is one of the most powerful DOE methods for analyzing of experiments. It is widely recognized in many fields particularly in the development of new products and processes in quality control. The salient features of the method are as follows:

a. A simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost.

b. Help arrive at the best parameters for the optimal conditions with the least number of analytical investigations.

c. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.

d. Can include the noise factor and make the design robust.

e. Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists.

Taguchi defines three quality characteristics in terms of signal to noise (S/N) ratio which can be formulated for different categories which are as follows:

a. Nominal and small are best characteristics

Data sequence for surface finish and tool wear, which are lower-the-better performance characteristics, are pre processed as per equations.

S/N = -10 log (ŷ/s2y)…………………1,

S/N = -10 log ((l/n) (Σy2))…………….2

b. Larger is best characteristics

Data sequence for material removal rate, which is higher-the-better performance characteristics, is pre processed as per equation 3.

S/N = -10 log ((1/n) (Σ (1/y2))……..…3,

Where, y is value of response variables and n is the number of observations in the experiments. Taguchi method- based design of experiments involved following steps,

a. Definition of the problem
b. Identification of noise factors
c. Selection of response variables
d. Selection of control parameters and their levels
e. Identification of control factor interactions
f. Selection of the orthogonal array
g. Conducting the matrix experiments (experimental procedure and set-ups)
h. Analysis of the data and prediction of optimum level

a. Definition of the problem

A brief statement of the problem under investigation is "To optimize the turning process parameters to minimize surface roughness, increase tool life and maximize the material removal rate."

c. Identification of noise factors

The environment in which experiments are performed is the main external source of variation of performance of turning process. Some examples of the environmental noise factors are temperature, vibrations and human error in operating the process.

d. Selection of response variables

In any process, the response variables need to be chosen so that they provide useful information about the performance of the process under study. Various parameters used while designing the experiments. By considering all parameters given below and by taking literature review as technical base Surface finish (Ra) is chosen as response variables.

e.Selection of control parameters and their levels:

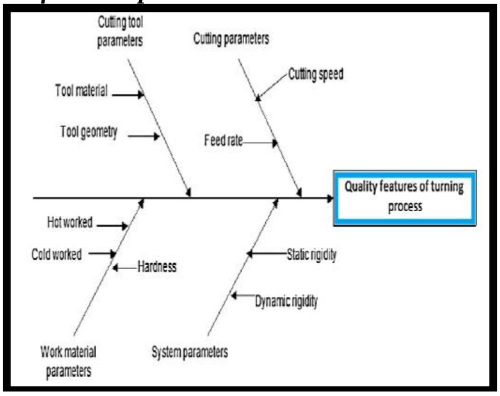


Figure:1. Fishbone diagram of cause of effect

The process parameters affecting the characteristics of turned parts are: cutting tool parameters, tool geometry and tool material; work piece related parameters- metallographic, hardness, etc.; cutting parameters- cutting speed, feed, depth of cut, DRY cutting and wet cutting, use of minimum quantity lubricant.

4. Selection of orthogonal array

Selection of particular orthogonal array from the standard O.A depends on the number of factors, levels of each factor and the total degrees of freedom.

i) Number of control factors = 5
ii) Number of levels for first four control factors = 4
iii) Number of levels for fifth control factor = 2
iv) Degree of freedom of each factor= number of level-1
v) Degree of freedom of first four control factors = 4-1=3
vi) Degree of freedom of fifth control factors = 2-1=1
vii) Total degrees of freedom of factors = sum of Degree of freedom of all factors= (3+3+3+3+1) =13
viii) Minimum number of experiments to be conducted =13+1=14.

Based on these values and the required minimum number of experiments to be conducted (14), the nearest O.A. fulfilling this condition is L16 .

Table:-1 Design of Experiments - Taguchi Array (L16)

Sr. No	CUTTING SPEED (m/min)	FEED RATE (mm/rev)	DEPTH OF CUT (mm)	NOSE RADIUS (mm)	CUTTING CONDITION
1	52	0.15	0.5	0.4	DRY
2	52	0.20	1.0	0.8	DRY
3	52	0.25	1.5	1.0	MQL
4	52	0.30	2.0	1.2	MQL
5	105	0.15	1.0	1.0	MQL
6	105	0.20	0.5	1.2	MQL
7	105	0.25	2.0	0.4	DRY
8	105	0.30	1.5	0.8	DRY
9	158	0.15	1.5	1.2	DRY
10	158	0.20	2.0	1.0	DRY
11	158	0.25	0.5	0.8	MQL
12	158	0.30	1.0	0.4	MQL
13	210	0.15	2.0	0.8	MQL
14	210	0.20	1.5	0.4	MQL
15	210	0.25	1.0	1.2	DRY
16	210	0.30	0.5	1.0	DRY

5. Selection of work and tool material

5.1 Test specimen

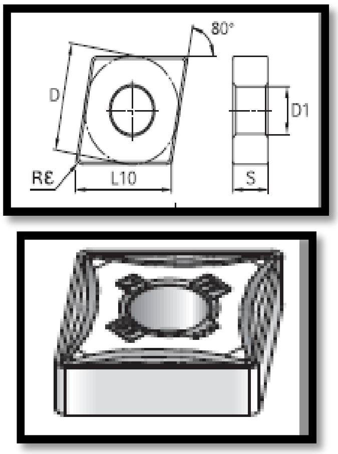
The work material used for the present study is EN24. EN24 is high tensile alloy steel well-known for its wear resistance properties and also where high strength properties are required.

Table:-2 Chemical composition of EN24

Chemical composition of EN24							
C	**SI**	**MN**	**S**	**P**	**Cr**	**Mo**	**Ni**
0.36/0.44	0.10/0.35	0.45/0.70	0.040 max	0.035 max	1.00/1.40	0.20/0.35	1.30/1.70

5.2 Cutting Tool

The recently developed tool materials like coated carbides have improved the productivity levels of difficult to machine materials. Table 5.2 gives the specification of different tool material. The coated carbide tool reduces wear and tear between tool insert and workpiece. Thus coated carbide tool was selected for turning of cast iron. Cutting Tool used is carbide insert tool CNMG120408 & CNMG120412 (ISO catalog Number).



6. Experimentation

The experiment was performed on CNC spinner 15 lathe machine as per experimental scheme shown in fig 2 consist of CNC hydraulic Chuck in which the workpiece was fixed. The Magnetic base sensor of VM- 6360 attached with base end of cutting tool insert for measurement of vibration. The MQL setup is also arranged for developing different type of cutting condition.

Figure:-2 Experimental setup

First the working of Vibrometer was checked taking some runs on EN24 (D=74mm). Then according to the experiment designed the cutting parameters are adjusted in the CNC lathe machine. The work piece was given initial roughing pass. Sixteen equal parts of 75mm Diameter and 80mm length were cut and arrange for experimentation. So taking the different parameters and changing the different nose radius inserts the readings are taken for analysis. The sixteen experiments were performed by using different setting of parameters and after the experimentation surface roughness and vibration were measured by probe type advance surface roughness tester and VM 6360 Vibrometer respectively.

Table:-3 Experimental results for Surface roughness, Vibration and S/N ratio

Run	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Nose radius (mm)	Cutting condition	Surface roughness Ra (um))	Signal to noise ratio	Vibration (peak amplitude mm/sec2)	Signal to noise ratio
1	52	0.15	0.5	0.4	DRY	3.3	-10.370	17.2	-24.711
2	52	0.2	1	0.8	DRY	3.35	-10.501	26.38	-28.425
3	52	0.25	1.5	1	MQL	2.5	-7.959	35.78	-31.073
4	52	0.3	2	1.2	MQL	2.08	-6.361	42.8	-32.629
5	105	0.15	1	1	MQL	1.3	-2.279	31.17	-29.875
6	105	0.2	0.5	1.2	MQL	2.56	-8.165	60.98	-35.704
7	105	0.25	2	0.4	DRY	3.77	-11.527	80.6	-38.127
8	105	0.3	1.5	0.8	DRY	1.7	-4.609	95.8	-39.627
9	158	0.15	1.5	1.2	DRY	1.14	-1.138	65.2	-36.285
10	158	0.2	2	1	DRY	1.25	-1.938	98.8	-39.895
11	158	0.25	0.5	0.8	MQL	1.08	-0.668	112.62	-41.032
12	158	0.3	1	0.4	MQL	3.45	-10.756	130.62	-42.320
13	210	0.15	2	0.8	MQL	1.15	-1.214	102.8	-40.240
14	210	0.2	1.5	0.4	MQL	2.02	-6.107	145.8	-43.275
15	210	0.25	1	1.2	DRY	1.38	-2.798	152.7	-43.677
16	210	0.3	0.5	1	DRY	1.8	-5.105	182.12	-45.207

7. Experimental Data Analysis

Minitab 15 software was used as it provides an effortless method to create, edit and update graphs. Also it provides a dynamic link between a graph and its worksheet that helps in updating the graph automatically whenever the data is changed. Its appearance and easy to use enhancements further add to its advantages.

Data analysis has been carried out by the procedural hierarchy as shown below.

1. Computation of (Signal-to-Noise Ratio) S/N ratio of experimental data. For calculating S/N ratio of
2. Ra, MRR and Vibration, formula of S/N ratio has been selected from equation 1,2 &3 according to the objective of optimization.
3. ANOVA is carried out to find out the contribution of each parameter on the turning process.
4. The predicted optimal setting has been evaluated from Mean Response.
5. Finally optimal setting has been verified by confirmatory test.

7.1 Taguchi Analysis (Signal to Noise ratio):

The Mean S/N Ratio is used to find out Optimal Level for Each Parameter and Rank of the parameter. The Rank of the parameter shows that which parameter is most effective. The mean S/N ratio for each factor at levels 1, 2, 3and 4 can be calculated by averaging the S/N ratios for the experiments. Fig. 6.1, fig. 6.5 shows the S/N response graph for surface roughness,and vibration respectively.

Table:-3 Response Table for Signal to Noise Ratios (SURFACE ROUGHNESS) Smaller is better

Symbol	Parameter	Mean S/N Ratio				Delta (Max-Min)	Rank
A	CUTTING SPEED (m/min)	-8.80	-6.65	-3.63	-3.81	4.99	2
B	FEED RATE (mm/rev)	-3.75	-6.68	-5.74	-6.71	2.96	3
C	DEPTH OF CUT (mm)	-6.08	-6.58	-4.95	-5.26	1.63	4
D	NOSE RADIUS (mm)	-9.69	-4.25	-4.32	-4.62	5.44	1
E	CUTTING CONDITION	-6.00	-5.44			0.56	5

Table:-4 Response Table for Signal to Noise Ratios (VIBRATION) Smaller is better

Symbol	Parameter	Mean S/N Ratio				Delta (Max-Min)	Rank
A	CUTTING SPEED	-29.21	-35.83	-39.88	-43.10	13.89	1
B	FEED RATE (mm/rev)	-32.78	-36.82	-38.48	-39.95	7.17	2
C	DEPTH OF CUT (mm)	-36.66	-36.07	-37.57	-37.72	1.65	3
D	NOSE RADIUS (mm)	-37.11	-37.33	-36.51	-37.07	0.82	4
E	CUTTING CONDITION	-36.99	-37.02			0.02	5

7.2 Analysis of variance (ANOVA)

The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output performance characteristics. In the analysis, the sum of squares and variance are calculated. F-test value at 95 % confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated.

Table:-5 Analysis of Variance for surface roughness

Source	Df	Seq ss	Adj ss	Adj ms	F	P	Contribution(%)
Cutting speed	3	3.813	3.813	1.271	1.27	0.469	29.37
Feed rate	3	0.845	0.845	0.282	0.28	0.838	6.51
Depth of cut	3	0.593	0.593	0.198	0.2	0.891	4.57
Nose radius	3	5.58	5.58	1.86	1.86	0.369	42.98
Cutting condition	1	0.15	0.15	0.15	0.15	0.736	1.16
Error	2	2.002	2.002	1.001			15.42
Total	15	12.983	12.983	4.762			100

Table:-6 Analysis of Variance for vibration

Source	Df	Seq ss	Adj ss	Adj ms	F	P	Contribution (%)
Cutting speed	3	29054.9	29054.9	9685	1422.64	0.001	77.98
Feed rate	3	7342.6	7342.6	2447.5	359.52	0.003	19.71
Depth of cut	3	300.5	300.5	100.2	14.71	0.064	0.81
Nose radius	3	365	365	121.7	17.87	0.053	0.98
Cutting condition	1	197.6	197.6	197.6	29.03	0.033	0.53
Error	2						0.00
Total	15	37260.6	37260.6	12552			100.00

8. Results and Discussion

For surface Roughness the objective is to minimize it, therefore for calculating the S/N ratio smaller the better S/N ratio is used and S/N ratio is calculated for each experiment and mean of S/N ratio is also calculated for each parameter. The mean of S/N ratio is calculated to find the rank of parameter and rank of parameter shows that which parameter is most effective to the turning process. From the mean S/N ratio at each level, maximum S/N ratio is selected which indicates the optimal level for that parameter. For Cutting speed the maximum S/N ratio is- 3.63DB at A3 .This indicates the optimal level for cutting speed. Similarly for Feed, depth of Cut, Nose radius and cutting condition the minimum S/N ratio is at B1, C3, and D2and E2. Therefore, optimal parameter for Minimum Surface roughness is at level (A3 B1 C3 D 2and E4) shown in fig.3 i.e. Cutting Speed = 158 m/min, Feed = 0.15 mm/rev, Depth of Cut = 1.5, Nose radius = 0.8 mm, Cutting Condition = MQL.

For vibration the objective is to minimize it, smaller the better S/N ratio is used and S/N ratio is calculated for each experiment and mean of S/N ratio is also calculated for each parameter. The mean of S/N ratio is calculated to find the rank of parameter and rank of parameter shows that which parameter is most effective to the turning process. From the mean S/N ratio at each level, maximum S/N ratio is selected which indicates the optimal level for that parameter. For Cutting speed the maximum S/N ratio is 29.21DB at A1 .This indicates the optimal level for cutting speed. Similarly for Feed, depth of Cut, Nose radius and cutting condition the maximum S/N ratio is at B1, C2, D3 and E2. Therefore, optimal parameter for minimum is at level (A1 B1 C2 D3 E2) shown in the fig.4.i.e at Cutting Speed = 210 m/min, Feed = 0.3 m/min, Depth of Cut = 2mm, Nose Radius = 0.8 mm, Cutting Condition = MQL

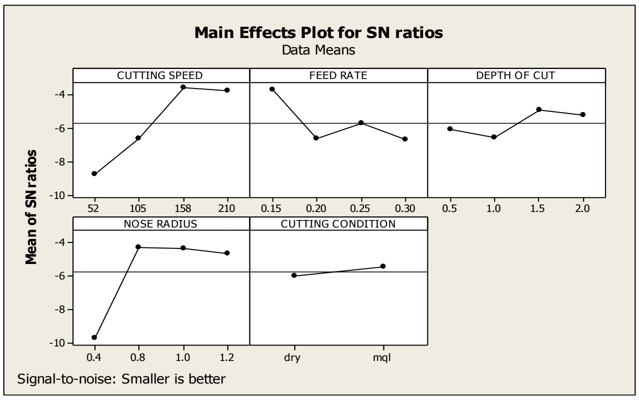


Figure:-3 Main effect plot for surface roughness

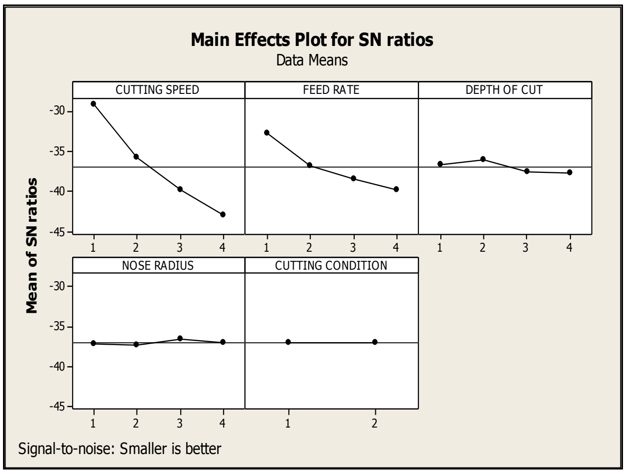


Figure:-4 Main effect plot for Vibration

9. Conclusion

The following are conclusions drawn based on the tests conducted on turning

I] For Surface Roughness:-

1) From the ANOVA, Table 5 and the P value, the nose radius is the most significant factor which contributes to the surface roughness i.e. 42.98% contributed by the nose radius on surface roughness.
2) The second factor which contributes to surface roughness is the cutting speed having 29.37%.
3) The third factor which contributes to surface roughness is the feed rate having 6.51%.

II] For Vibration:-

1) From the ANOVA, Table 6 and the P value, the cutting speed is the most significant factor which contributes to the surface roughness i.e. 77.98% contributed by the cutting speed on vibration.
2) The second factor which contributes to surface roughness is the feed rate having 19.71%.
3) So now it is found by this research how to use Taguchi's parameter design to obtain optimum condition with lowest cost, minimum number of experiments and industrial engineers can use this method.

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