Effect of Machining Parameters on Surface Roughness in Hard Turning Process

SUNIL P. MAGHODIYA
P.G. Scholar, M.E.[Production], L.D.R.P.-ITR, Gandhinagar

PROF. JAYESH V. DESAI
Asst. Prof. Mechanical Engineering Dept. LDRP-ITR, Gandhinagar
Gujarat (India)

Abstract:
The development of more wear-resistant tool materials such as Polycrystalline Cubic Boron Nitride (PCBN) and ceramics have made hard turning a potential alternative to grinding operations in the finishing of hard materials. The effect of machining parameters has long been an issue in understanding mechanics of turning. Machining parameters has significant influence on chip formation, heat generation, tool wear, surface finish and surface integrity during turning Therefore, an effort has been made in this research to evaluate the effect of machining parameters nose radius, cutting speed and feed rate on surface roughness when turning tool steel H-11 with CBN tool. Machining trials was performed based on full factorial design under dry condition on Lathe in which I have measured surface roughness. The combined effects of the process parameters on performance characteristics are investigated using ANOVA analysis. Results shows that nose radius and feed rate significantly affect surface roughness.

Keywords: *Full factorial design, Hard turning, Surface roughness*

1. Introduction

Hard turning is the process of machining hardened ferrous material with a hardness value more than 45HRC in order to obtain finished workpieces directly from hardened parts. The growth of hard turning process is indebted to the advent of new advanced tools such as Cubic Boron Nitride (CBN), Polycrystalline Cubic Boron Nitride (PCBN), Chemical vapor deposition (CVD), Physical Vapor Deposition (PVD) and Ceramic tools since 1970. Reduction in machining costs, elimination of cutting fluids, increase in the flexibility and efficiency, parthandling costs and finally decrease in the set-up times when compared to grinding process.The great advantage of hard turning is its dry environment, it is mostly carried out in the absence of lubricants[10].

One important parameter in the qualification of cut surfaces is their roughness, and its indexes. The roughness has great significance primarily at mating the sliding surfaces. This has been one more reason for the researchers' increased interest for a long time to predict these indexes for a given process within the specified cutting conditions. Several modeling procedures and techniques were worked-out, which essentially can be classified into four groups: l) analytical models, 2) experimental methods, 3) DoE (Design of Experiment)-based methods and 4) AI (Artificial Intelligence)-based methods [11].

2. Existing Research Efforts

Ilhan Asilturk et al. [7] have studied on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. The developed model can be used in the metal machining industries in order to determine the optimum cutting parameters for minimum surface roughness.

Dr. C. J. Rao et al.[9] have studied the significance of influence of speed, feed and depth of cut on cutting force and surface roughness while working with tool made of ceramic with an Al_2O_3+TiC matrix (KY1615)and the work material of AISI 1050 steel (hardness of 484 HV). Experiments were conducted using Johnford TC35 Industrial type of CNC lathe. Taguchi method (L27 design with 3 levels and 3 factors) was used for the experiments. Analysis of variance with adjusted approach has been adopted. The results have indicated that it is feed rate which has significant influence both on cutting force as well as surface roughness. Depth of cut has a significant influence on cutting force, but has an insignificant influence on surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters have significant influence on cutting force, whereas, none of the interaction effects are having significant influence on the surface roughness produced.

Varaprasad.Bh et al[10] have invested on to develop a model and predict tool flank wear of hard turned AISI D3 hardened steel using Response Surface Methodology (RSM). The combined effects of cutting speed, feed rate and depth of cut are investigated using contour plots and surface plots. RSM based Central Composite Design (CCD) is applied as an experimental design. Al_2O_3/TiC mixed ceramic tool with corner radius 0.8 mm is employed to accomplish 20 tests with six centre points. The adequacy of the developed models is checked using Analysis of Variance (ANOVA). Main and interaction plots are drawn to study the effect of process parameters on output responses.

Nexhat Qehaja et al.[11] have studied on model of surface roughness was developed based on the response surface method to investigates the machining parameters such as feed rate, tool geometry, nose radius, and machining time, affecting the roughness of surface produced in dry turning process. The experiment has been designed and carried out on the basis of a three level factorial design. Obtained results are in good accordance with the published results in the field, validating the effectiveness of regression analysis in modeling of surface roughness in dry turning process.

Shreemoy Kumar Nayak et al.[12] have studied the influence of different machining parameters such as cutting speed (Vc), feed (f) and depth of cut (t) on different performance measures during dry turning of AISI 304 austenitic stainless steel. ISO P30 grade uncoated cemented carbide inserts was used a cutting tool for the current purpose. L27 orthogonal array design of experiments was adopted with the following machining parameters: Vc= 25, 35, 45 m/min., f= 0.1, 0.15, 0.2 mm/rev. and t= 1, 1.25, 1.5 mm. Three important characteristics of machinability such as material removal rate (MRR), cutting force (Fc) and surface roughness (Ra) were measured. Attempt was further made to simultaneously optimize the machining parameters using grey relational analysis. The recommended parametric combination based on the studied performance criteria (i.e. MRR, Fc and Ra) was found to be Vc =45m/min, f=0.1mm/rev, t=1.25mm. A confirmatory test was also carried out to support the analysis and an improvement of 88.78% in grey relational grade (GRG) was observed

Dipti Kanta Das et al.[13] have studied on surface roughness during hard machining of EN 24 steel with the help of coated carbide insert. The experiment has been done under dry conditions. The optimization of process parameters have been done using Grey based Taguchi approach. Also the prediction models have been developed using regression analysis for surface roughness and adequacy has been checked. Good surface quality of roughness about 0.42 microns is obtained in hard machining. Using grey-based Taguchi approach, the optimal parametric combination for surface quality characteristics (Ra and Rz) have been obtained to be depth of cut: 0.4 mm, feed: 0.04 mm/rev and cutting speed: 130 m/min respectively. Feed is considered to be the most dominant parameter for both surface roughness parameters Ra and Rz. The prediction models have high correlation coefficient

(R^2 = 0.993 and 0.934). This is evident to be better fitting of the model and found to be high significance.

L B Abhanga et al,[14] have studied on turning process parameters on steel. Experiments have been conducted using factorial design, to study the effect of machining parameters such as cutting speed, feed rate, depth of cut, tool nose radius and lubricant on surface roughness while turning En-31 steel. The Results have been analyzed by the variance technique and the F-test, showing thereby that the cutting speed, feed rate, depth of cut, tool nose radius and lubricants have significant effect on measured surface roughness during turning steel.

Panda et al.[15] have studied on hard turning of EN 31 steel (55HRC) using TiN/TiCN/Al_2O_3 multilayer coated carbide inserts through Taguchi L16 orthogonal array design and investigates surface roughness under dry environment. The mathematical model has been developed for better prediction of responses using response surface methodology and correlated for its significance. The mathematical model presented high correlation coefficients (higher R^2 value) and fitted well. Feed is found to be most dominant parameter for affecting the surface roughness. A Taguchi technique has been utilized for parametric optimization of surface roughness. From the study, the potential and effectiveness of multilayer coated carbide insert has been noticed while turning hardened steels under dry environment.

3. Design of Experiment

DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels each within the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. The design of experiment is used to develop a layout of the different conditions to be studied. And experiment design must satisfy two objectives: first, the number of trials musty be determined; second, the conditions for each trial must be specified.

Here full factorial experiment is used; full factorial experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. Three factors are chosen the design becomes a 3 level 3 factors. The version 17 of the MINITAB software was used to develop the experimental plan for Orthogonal Array of full factorial experiment.

Table 1: Factors with Levels

Parameters	Level-1	Level-2	Level-3
Nose radius(mm)	1.2	0.8	0.4
Feed rate(mm/rev)	0.05	0.06	0.07
Cutting speed(m/min)	82	117	156

4. Experimental Setup

The lathe machine model HMT NH 22 is used; distance between both centers is 1000mm and spindle speed ranging from 35-2375rpm. Work piece material to be used- H11 tool steel 90mm diameter and 380mm length, work piece material hardness of 60HRC. The chemical composition of work piece material

Table 2: Chemical composition of H-11 tool steel

Element	carbon	silicon	manganese	phosphorus	sulphur	chromium	molybdenum	vanadium
Content (%)	0.350	0.890	0.382	0.031	0.025	4.840	1.370	0.290

Typical application of H-11 tool steel are for highly stressed structural parts such as aircraft landing gear, hot punches, die casting dies, hot shear blades, forging dies and extrusion tooling.

The cutting tool was SANDVIK KOROMANT CBN cutting insert with three different nose radius, designation of cutting insert CNGA120412, CNGA120408, CNGA120404, The inserts were rigidly mounted on a right hand style tool holder of SANDVIK KOROMANT and its ISO designation was DCLNR-2525 M112.

Fig. 1: Cutting tool inserts used in experiment

Surface roughness of the turned surface was measured using a portable surface roughness tester **Mitutoyo SJ210**

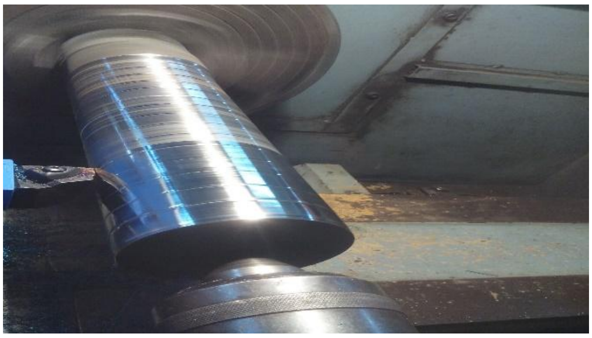


Fig. 2: Experiment performance

5. Experimental Result & Discussion

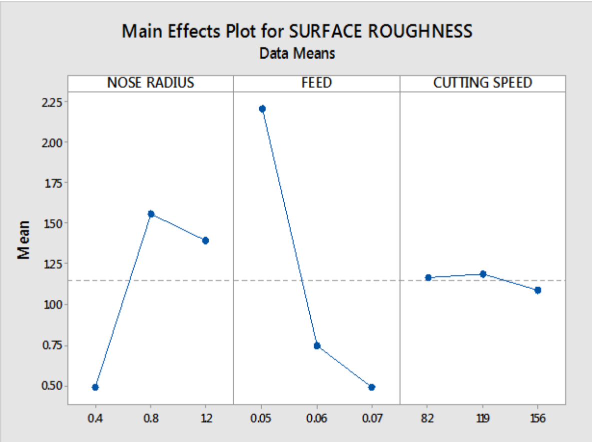
The effect of process parameters on the machining parameter is recorded in the table. The twenty seven (27) experiments done on the lathe machine based on the full factorial experiment and summarized in the following table.

Table 3: Design Layout and Experimental Results

Std Order	Run Order	Pt Type	Blocks	Nose radius(mm)	Feed (mm/rev)	Speed (m/min)	SR(µm)
1	1	1	1	0.4	0.05	82	0.556
2	2	1	1	0.4	0.05	119	0.542
3	3	1	1	0.4	0.05	156	0.505
4	4	1	1	0.4	0.06	82	0.487
5	5	1	1	0.4	0.06	119	0.51
6	6	1	1	0.4	0.06	156	0.452
7	7	1	1	0.4	0.07	82	0.442
8	8	1	1	0.4	0.07	119	0.45
9	9	1	1	0.4	0.07	156	0.464
10	10	1	1	0.8	0.05	82	3.672
11	11	1	1	0.8	0.05	119	4.165
12	12	1	1	0.8	0.05	156	3.012
13	13	1	1	0.8	0.06	82	0.765
14	14	1	1	0.8	0.06	119	0.53
15	**15**	**1**	**1**	**0.8**	**0.06**	**156**	**0.43**

16	16	1	1	0.8	0.07	82	0.511
17	17	1	1	0.8	0.07	119	0.482
18	18	1	1	0.8	0.07	156	0.486
19	19	1	1	1.2	0.05	82	2.365
20	20	1	1	1.2	0.05	119	2.224
21	21	1	1	1.2	0.05	156	2.865
22	22	1	1	1.2	0.06	82	1.124
23	23	1	1	1.2	0.06	119	1.315
24	24	1	1	1.2	0.06	156	1.112
25	25	1	1	1.2	0.07	82	0.624
26	26	1	1	1.2	0.07	119	0.467
27	27	1	1	1.2	0.07	156	0.465

Here from the experiment we get minimum surface roughness 0.430 µm at set no.15 were nose radius 0.8 mm, feed rate 0.06mm/rev and cutting speed 156m/min. this is our optimum cutting condition. The influence of control factor can be more clearly presented with response graph as shown in figure



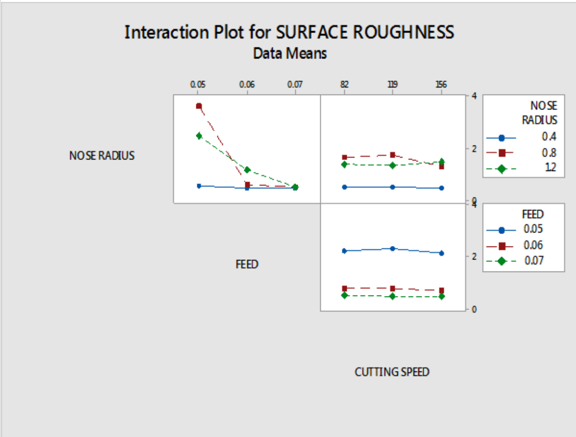


Fig. 3: Main effect plot for surface roughness **Fig. 4: Interaction Plot of Surface Roughness**

Nose radius: at 0.4 mm nose radius surface roughness is minimum and increasing nose radius to 0.8 mm surface roughness increase and further increasing nose radius to 1.2 mm surface roughness is decreasing.

Feed: as feed rate increasing surface roughness decreasing continuously.
Speed: As speed increase from 82m/min to 119m/min Surface roughness slightly increase while further increasing speed to 156 m/min surface roughness slight decrase.

6. ANOVA analysis

The analysis of variance is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not.

Table 4 ANOVA analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	18	31.3791	1.74328	21.98	0.000
NOSE RADIUS	2	5.9898	2.99488	37.76	0.000
FEED	2	15.5519	7.77595	98.04	0.000

CUTTING SPEED	2	0.0514	0.02571	0.32	0.732
2-Way Interactions	12	9.7860	0.81550	10.28	0.001
NOSE RADIUS*FEED	4	9.4701	2.36752	29.85	0.000
NOSE RADIUS*CUTTING SPEED	4	0.2790	0.06974	0.88	0.517
FEED*CUTTING SPEED	4	0.0369	0.00923	.12	0.973
Error	8	0.6345	0.07932		
Total	26	32.0136			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.281634	98.02%	93.56%	77.42%

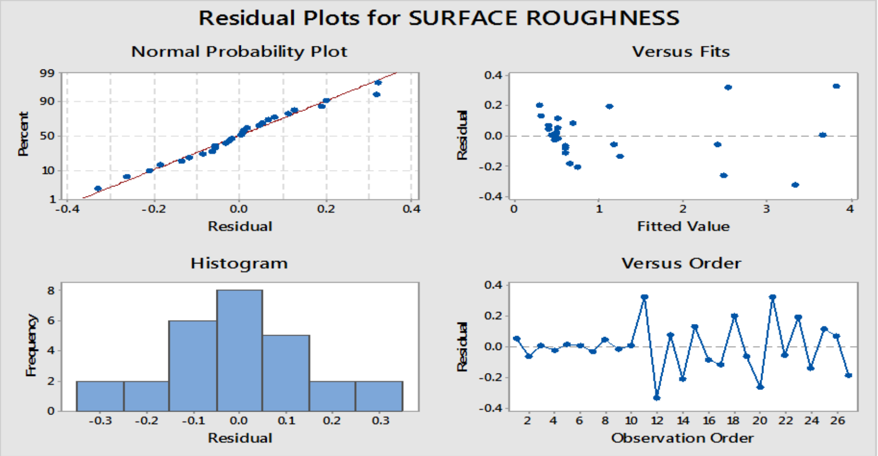


Fig. 5: Residual plots for surface roughness

From anova analysis we can conclude that nose radius and feed rate significantly effect surface roughness because in analysis the P-Value is below 0.005 which supports null hypotheses. Above analysis shows the percentage contribution of individual process input parameters of Hard turning on H-11 for surface roughness. The percentage contribution of Nose radius is 18.6339%, Feed rate is 48.732% and cutting speed is 0.0134%.

7. Conclusion

In the present study, an attempt has been made to investigate the effect of process parameters nose radius, feed rate and cutting speed on the performance characteristics like surface roughness in finish hard turning of H-11 steel hardened at 60 HRC with CBN tool.

Optimum cutting condition in hard turning of H-11 steel with CBN tool was achieved with a nose radius = 0.8mm, Feed rate = 0.06mm/rev and cutting speed = 156m/min based on lower surface roughness value(0.43µm). Contribution of cutting conditions on surface roughness as mentioned below:

Here after experimentation ANOVA analysis is conducted and percentage contribution of each factor are, 18.63% of nose radius, 48.73% of feed rate and 0.013% of cutting speed. Here feed rate and nose radius is significantly affect surface roughness while speed has insignificant effect on surface roughness. For lower surface roughness lower nose radius and higher feed rate should be used.The proposed experimental and statistical approaches bring a reliable methodology to optimize and to improve the hard turning process. Also, they can be extended efficiently to study other machining processes.

8. Future Scope

Al though the Hard Turning experiment has been thoroughly investigated for H-11 tool steel work material, still there is a scope for further investigation. The following suggestions may useful for future work:

- Hard turning process can be analyze by using various geometry of cutting tool (e.g. rake angle, cutting edge angle)
- Effect of force, temperature and stress produce during hard turning can be evaluated.
- Various analytical models like force and wear can be evaluated.
- Effect of vibration at different speed during hard turning can be studied.

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