International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

Optimization of Cutting Parameters in Hard Turning of AISI 4340 Steel

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Abstract*— The turning of hardened steels has been applied in many cases in production. It is an important process because all manufacturers are continually seeking ways to manufacture their parts with lower cost, higher quality, rapid setups, lower investment, and smaller tooling inventory while eliminating non-value added activities. Currently, the most important problem is concerned with the properties of the surface finish. This paper investigates the effect on surface finish and tool wear in a continuous dry turning of hardened steel when using a ceramic wiper tools. This report describes about the hard turning of AISI 4340 alloy steel by varying various parameters. The hard turning parameters are: Cutting speed, Feed and Depth of cut. The main objectives of this project, study the effect of parameters such as cutting speed, feed, depth of cut on surface roughness, tool wear and cutting force during the hard turning of AISI 4340alloy steel using ceramic wiper tool and the effect of various process parameters on hard tuning and optimize the cutting parameters. The dry turning experiments were performed on hardened AISI 4340 steel material using ceramic wiper tool .AISI 4340 steel having hardness: 48 (48–52) HRC was used.

***Keywords*— Hard turning, surface roughness, taguchi's method.**

I. Introduction

Hard turning attracts great interests since it potentially provides an alternative to conventional grinding process for machining high hardness, high precision components in small production [1]. During the past few years, unprecedented progress has been made in the hard turning. The greatest advantage of using hard turning is the reduced machining time and complexity required to manufacture metal parts.

In order to substitute grinding process and minimize tool wear, cutting parameters in hard turning are generally adapted for finishing operations [3]. Small depth of cut and low feed rates are chosen to improve finished surface and reduce the mechanical and thermal impacts on the tools to acceptable limits. Many studies have been conducted to investigate the performance of ceramics tools in the cutting of various hardened materials. Wiper inserts are increasingly being utilized during the last years. The influences of the wiper inserts on the surface roughness were described in turning [2]. While machining, the wiper ceramic performed better in respect to surface roughness and tool wear whereas the conventional ceramic exhibited less machining force and power.

II. Experimental procedure

A. Material, workpiece and tool

AISI 4340 has been selected as work piece Material .It widely used for aircraft landing gear, power transmission gear, shaft and other parts. The diameter and Length of work piece was 65 mm and 360 mm respectively. Chemical composition of this material is Carbon 0.38 to 0.48%, Chromium 0.7 to 0.9%, Manganese 0.6 to0.8, Molybdenum 0.2 to 0.3, Nickel 1.65 to 2%, Phosphorus 0.035 max, Silicon 0.15 to0.30%, Sulphur 0.04max.

Ceramic tools reference CC6050WH, CNGA120408S01525WH (ISO) were used to machine the AISI 4340 steel with a geometry as follows: rake angle -6°, 6° clearance angle and 75° approach edge. All ceramic wiper tools are used.

The hard turning of work piece is conducted on centre Lathe with variable feed and speed drive having following Specifications:

Height of centre: 175 mm, Swing over bed: 350mm, Swing over slide: 190mm, Swing in gap: 550mm, Width of bed: 240mm, Spindle speed NO. 8: 60 To 1025 RPM, Cross slide travel: 200mm, Top slide travel: 125mm, Net weight: 700 kg, Lead screw: 4 TPI, Power required: 1.5W/2H.P, Bed length: 4'.5"/600mm

The measurements of surface roughness (Ra,) for each cutting condition were obtained from a Surfce tester SJ210 Mitutoyo roughness meter. Tool wear is measured using Metzer tool makers microscope and machining force is measured using a dynamometer. The measurements were repeated three times out of three generatrices equally positioned at 120° and the result is an average of these values for a given machining pass.

B. Experimental design

Design of Experiments (DOE) is a powerful statistical technique to study the effect of multiple variables simultaneously. An experimental plan is produced which tells the experimenter where to set each test parameter for each run of the test [6]. The response is then measured for each run. The method of analysis is to look for differences between response (output) readings for different groups of the input changes. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.

In this study, three controllable variables, namely, cutting speed, feed rate and depth of cut has been selected. In the machining parameter design, three levels of the cutting parameters were selected, shown in Table 1.

TABLE 1. Hard turning process parameters

Parameter	**Unit**	**Levels**			**Response**
		1	**2**	**3**	
Cutting speed	m/min	100	140	180	**1. Surface roughness** **2. Tool wear** **3. Cutting force**
Feed	mm/rev	0.1	0.125	0.15	
Depth of cut	mm	0.4	0.6	0.8	

C. Taguchi's Design of Experiment

Taguchi method is a traditional approach for robust experimental design that seeks to obtain a best combination set of factors/levels with the lowest societal cost solution to achieve customer requirements. Taguchi's approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community. In the Taguchi design method the design parameters (factors which can be controlled) and noise factors (factors which can't controlled), which influence product quality, are considered [5]. The main trust of the Taguchi technique is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of quality characteristic with minimum variation. Taguchi design provides a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. Experimental design methods were developed in the early of 20th century and have been extensively studied by the statistician since then, but they were not easy to use by practitioners. Taguchi recommended using solutions in metal cutting problems to optimize the parameters.

D. Experimental Procedure

As per table 1, L9 orthogonal array of "Taguchi method" has been selected for the experiments in MINITAB 16. Each 9 experiments will carry out in dry turning. Surface roughness, tool wear and machining force has been selected as response variable. All these data are used for the analysis and evaluation of the optimal parameters combination. Experiment result as shown in Table2. The experimental procedure are, in the following order (1) define the independent input variables and the desire responses with the design constants, (2) adopt an experimental design plan, (3) perform the taguchi's experimental design, (4) calculate the statistical analysis of variance (ANOVA) for the independent input variables in order to find which parameter significantly affects the desired response, then, (5)Optimize and conduct confirmation experiment and verify the predicted performance characteristics[3].

III. **RESULT AND DISCUSSION**

The Table 2 illustrates the responses of surface roughness, tool wear and machining force. Analyses were done with ANOVA results for the identifying factors which are affecting the performances. Also the percentage of contribution of each source to the total variation indicates the degree of influence on the result by each source.

TABLE 2. Details of experiments and results.

Expt.No.	Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Surface roughness Ra(µm)	Tool wear (mm)	Machining force (N)
1	100	0.1	0.4	1.225	0.039	259.42
2	100	0.125	0.6	0.879	0.029	431.27
3	100	0.15	0.8	1.063	0.035	557.01
4	140	0.1	0.8	1.011	0.030	403.00
5	140	0.125	0.4	0.778	0.024	298.98
6	140	0.15	0.6	1.114	0.046	445.83
7	180	0.1	0.6	0.852	0.042	319.77
8	180	0.125	0.8	0.698	0.036	567.58
9	180	0.15	0.4	0.996	0.042	286.31

Taguchi's method of analyzing means of the S/N ratio using conceptual approach involves graphical method for studying the effects and visually identifying the factors that appear to be significant. The rank indicates the dominant machining parameter.

A. Surface Roughness

In the experiment, the desired characteristic for surface roughness is lower the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i{}^2)\right] \qquad (1)$$

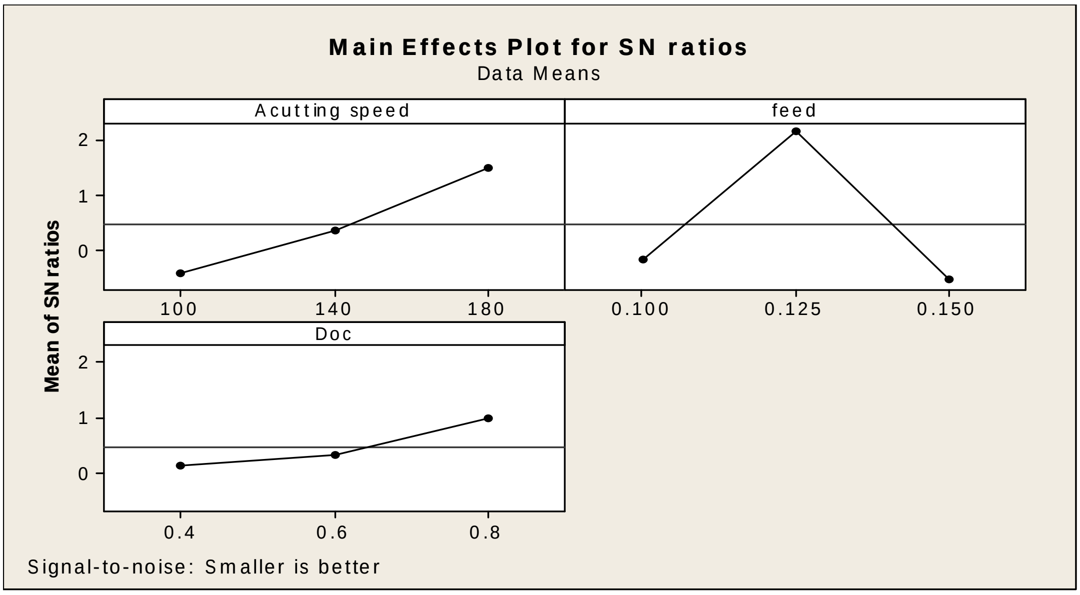

Fig.1 Signal to Noise Plot for surface roughness.

TABLE 3. Response Table for surface roughness S/Noise Ratios (Smaller is better)

Level	Cutting speed	Feed	Doc
1	-0.4221	-0.1709	0.1272
2	0.3621	2.1380	0.3235
3	1.4957	-0.5314	0.9850
Delta	1.9178	2.6693	0.8577
Rank	2	1	3

Table 3 shows the response table of Signal to Noise ratios for surface roughness. Based on this analysis, low surface roughness is obtained at cutting speed (180m/min), Feed rate (0.125mm/rev), and Depth of cut (0.8mm). In the analysis, feed is shown as the most influencing parameter followed by cutting speed and depth of cut.

TABLE 4. Analysis of variance for surface roughness

Source	Degrees of freedom	Sum of squares	Mean of squares	F	P	% contribution
Cutting speed	2	5.5779	2.7889	8.05	0.111	27.79
Feed	2	12.5860	6.2930	18.16	0.052	62.71
Doc	2	1.2117	0.6059	1.75	0.364	6.03
Error	2	0.6931	0.3466			3.45
Total	8	20.0687				100

The ANOVA results in Table 4 the percentage contribution of various factors to surface roughness is identifiable. Here, feed rate is the most influencing factor followed by cutting speed. The percentage contribution of feed rate and cutting

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

speed towards surface roughness is 62.71% and 27.79% respectively. Also Doc is which indicates that Doc has least contribution towards surface roughness.

The optimal combination is:

Cutting speed = 180m/min
Feed rate = 0.125mm/rev
Doc = 0.8mm

Regression equation

Regression equation is:

Ra = 1.42 - 0.00259 Cutting speed + 0.57 Feed - 0.286 Depth of cut

B. Tool Wear

The desired signal to noise ratio for tool wear is to be lower the better, equation (1).

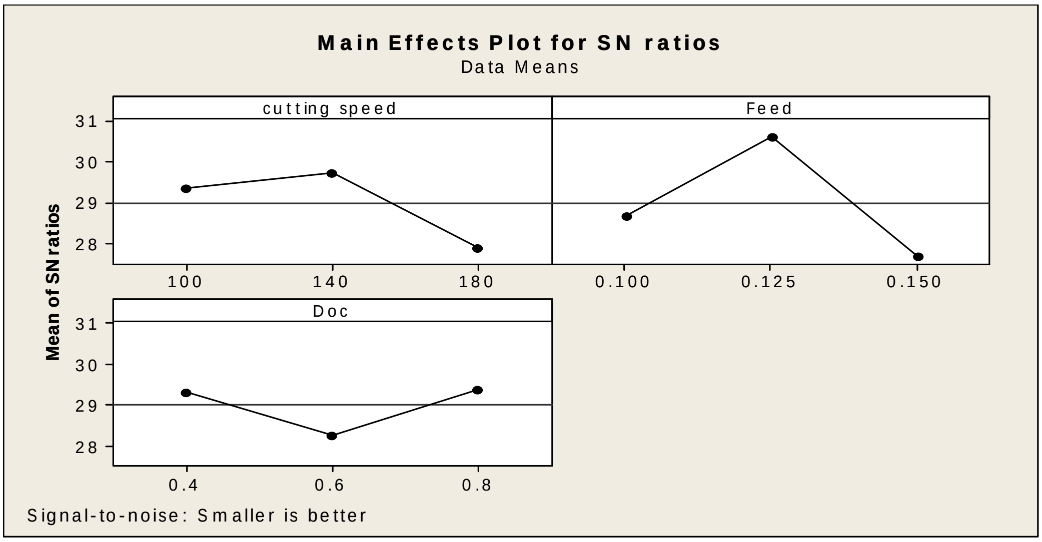

Fig.2. Signal to Noise Plot for Tool Wear

TABLE 5. Response table for tool wear

Level	Speed	Feed	Doc
1	29.36	28.69	29.34
2	29.76	30.63	28. 26
3	27.90	27.69	29.42
Delta	1.86	2.93	1.15
Rank	2	1	3

Table 5. Show the response table of Signal to Noise ratios for Tool wear. Based on this analysis, low surface roughness is obtained at cutting speed (140m/min), feed rate (0.125mm/rev), and depth of cut (0.8mm). In the analysis, feed is shown as the most influencing parameter followed by speed and depth of cut.

TABLE 6. Aanalysis of variance for tool wear

Source	Degrees of freedom	Sum of squares	Mean of squares	F	P	% of contribution
Cutting Speed	2	5.726	2.863	0.88	0.533	20.39
Feed	2	13.331	60665	2.04	0.329	47.47
Depth of cut	2	2.502	1.251	0.38	0.723	8.90
Error	2	6.526	3.263			23.24
Total	8	28.085				100.00

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The ANOVA results in Table 6 shows the percentage contribution of various factors to Tool wear is identifiable. Here, Feed rate is the most influencing factor. The percentage contribution of feed rate towards tool wear is 47.47%. The parameters which have least contribution towards tool wear are cutting speed (20.39%) and depth of cut (8.90%).

The optimal combination obtained as :
Cutting speed = 140 m/min
Feed = 0.125mm
Depth of cut = 0.8mm

Regression equation

The regression equation is:

Tool wear = 0.0172 + 0.000074 cutting speed + 0.082 Feed **-** 0.0031 Depth of cut

C. Machining force

In the experiment, the desired characteristic for surface roughness is lower the better.

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{{y_i}^2}\right)\right] \quad (2)$$

Machining force: $\mathbf{F_m} = \sqrt{(F_c^2 + F_f^2 + F_t^2)}$ (3)

Where,

Fc: Cutting force,
Ft: Radial force,
Fr: Feed force
Unit of machining force (N)

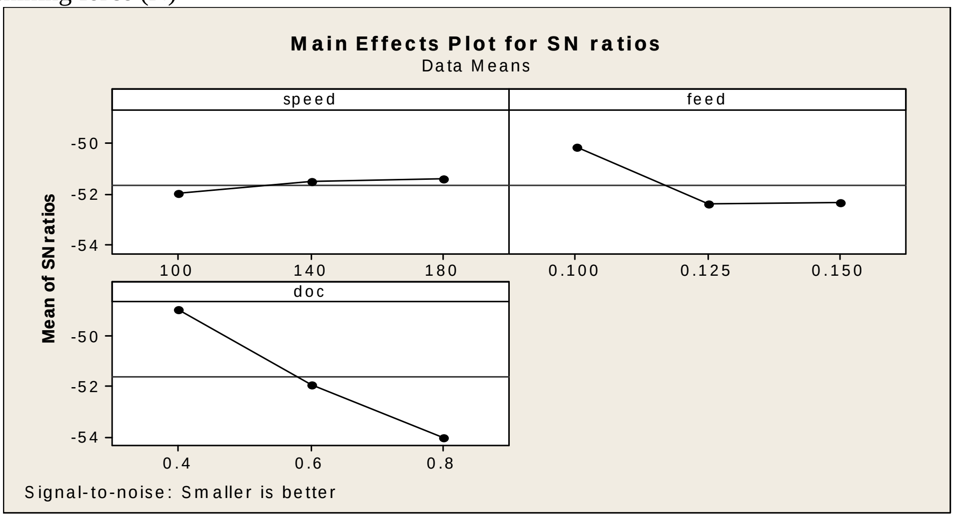

Fig.3. Signal to Noise Plot for Machining Force.

TABLE 7. Response table for Machining Force

Level	Cutting speed	Feed	Depth of cut
1	-51.96	-50.16	-48.98
2	-51.53	-52.43	-51.93
3	-51.44	-52.35	-54.03
Delta	0.53	2.27	5.06
Rank	3	2	1

Table 7 shows the response table of Signal to Noise ratios for machining force. Based on this analysis, high machining force is obtained at Depth of cut (0.4 mm), Feed rate (0.1 mm/rev), and speed (180 m/min). In the analysis, depth of cut is the most influencing parameter followed by feed and cutting speed.

TABLE 8. Analysis of variance for machining force.

Source	Degrees of freedom	Sum of squares	Mean of squares	F	P	% of contribution
Cutting speed	2	0.4710	0.2355	0.45	0.690	0.93
Feed	2	9.9260	4.9630	9.46	0.096	19.78
Depth of cut	2	38.7277	19.3639	36.92	0.026	77.19
Error	2	1.0489	0.5245			
Total	8	50.1736				

The ANOVA results in Table 8.shows the percentage contribution of various factors to machining force is identifiable. Here, Depth of cut is the most influencing factor followed by feed. The percentage contribution of depth of cut and towards machining force is 77.19% and 19.78% respectively. Also the F value of cutting speed is much more than that of table value (4.46) which indicates that it has least contribution towards machining force.

The optimal combination is:
Cutting speed = 180m/min
Feed = 0.1mm/rev
Depth of cut = 0.4mm

Regression equation

The regression equation is:
Machining Force = 232 - 0.31 cutting speed + 2046 feed - 81 Depth of cut

IV. CONCLUSIONS

From the experiments, it is found that the surface roughness is significantly influenced by feed and cutting speed; however depth of cut has very less effect during hard turning of AISI 4340 alloy steel. Most optimal hard turning parameter over the selected range of hard turning parameters were obtained from Taguchi analysis using signal to noise ratio as cutting speed (180 m/min), feed (0.125mm/rev), and depth of cut (0.8mm).

It is found that for toll wear during hard turning of AISI 4340 alloy steel, feed has significant influence and depth of cut is the least influential of all. Based on ANOVA, the optimal condition is obtained at cutting speed (140 m/min), feed (0.125mm/rev), and depth of cut (0.8mm).

During the study of cutting force in hard turning of the AISI 4340, it was found that depth of cut and feed are the most influencing parameters. The effect of cutting speed on the cutting force in the hard turning is negligible. Based on the analysis the optimal condition is obtained are cutting speed (180 m/min), (0.1 mm/rev), and depth of cut (0.4 mm).

There is further scope of study in the hard turning of AISI 4340 by expanding the range of hard turning parameters beyond the selected range of values in this work and application of proper cooling mechanism.

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