Optimizing Surface Roughness and Flank Wear on Hard Turning Process Using Taguchi Parameter Design

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Abstract -**This paper presents an application of the Taguchi method parameter design to optimize the surface roughness, tool wear and cutting force by hard turning process. The Taguchi parameter design method is an efficient method in which response variable can be optimized, given various controls and using fewer experimental runs. Hard turning is the latest trend in all manufacturing industries and it is a profitable alternative to grinding. The hard turning removes unwanted material in a single cut rather than grinding in order to reduce process time, set up time, operating cost, surface roughness and to produce components economically. In the process of analyses, material having hardness between 54-58 was considered and three CBN cutting tool were used to conduct 18 tests. The response of surface roughness and flank wear taken for discussion and analyses. The experimental results show that there is a good agreement between surface roughness and flank wear both by equations and experiments by Taguchi method.**

Key words: **Cutting force, Flank wear, Surface roughness, Taguchi Method**

1. INTRODUCTION

The optimization of machining processes is essential for the achievement of high responsiveness of production, which provides a preliminary basis for survival in to-day's dynamic market conditions [1]. Production research activities in a real production environment [2] supported by statistical experimental procedures [3] enable continuous improvement of production processes and further cost reductions [4]. The Taguchi method of experimental design is one of the widely accepted techniques for off line quality assurance of products and processes. The Taguchi method is a traditional approach for robust experimental design that seeks to obtain a best combination set of factors /levels with the lowest cost societal solution to achieve customer requirements [5]. In the Taguchi method the parameters factors which can be controlled and noise factors which can't be controlled and which influence product qualities are considered [5]. The hard turning process is followed in all the engineering industries to finish turn the parts to form the near shape products. Hard turning operation is performed on materials having hardness between 60 to 65 HRC. The tests are conducted by using cutting speed, depth of cut and feed rate as main parameter and analysis was done based on the responses.

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II. TAGUCHI TECHNIQUES

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 [6]. 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 [7]. 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 [8]. 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 [9]. Taguchi recommended using solutions in metal cutting problems to optimize the parameters [10].

III. EXPERIMENTAL PROCEDURE

A. Equipments and Material

The objective of the experiments was to establish a relation between cutting speed, feed rate and depth of cut on surface roughness and flank wear. The work material was SCM 440 high strength alloy steel received in the form of 1000 mm length and 50 diameter long bar and cut to 350 mm length. The work material was skin turned to

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remove scales and centered on both sides to accommodate in the lathe centers. The work piece material was induction hardened between 54 to 58 HRC. The chemical and mechanical properties of the work material are given in the Table 1 and 2. The experiments were conducted in a Hass make CNC machine having spindle speed of 6000 rpm and power of the machine is 35 KW/HP. The cutting tool was CBN, manufactured by Mitsubishi having code MB8025 with three cutting edges. The tool holder used was MTJNL 2020K16N.

Table 1. Composition of SCM 440 alloy steel

Material	C %	Mn %	Cr.%	Mo. %
SCM 440	0.35 /0.43	0.75/1.00	0.80/0.75	0.15/0.25

Table 2. Mechanical Properties of SCM 440

Yield Strength (MPa)	Tensile Strength (MPa)	Hardness HRC
557	665	20 To 25

Table 3. Cutting parameters

Cutting Speed A	125	175	225
Depth of Cut B	0.20	0.30	0.40
Feed Rate C	0.04	0.05	--

Three levels were specified for cutting speed, depth of cut and twos level for feed rate. A total 18 experiments were designed by Taguchi method and are shown in the Table 4. The experiment was carried for a length of 200 mm. The surface roughness was measured using Mitutoyo Surftest SJ301 and the tool wear by Nikon make Toolmaker's Microscope fitted with Image Pro-Express version 5.1software designed to run under Microsoft Windows 32 bit system which can capture the area of the wear.

B. Experiment Results and Analyses

As experiment was developed for assessment of surface roughness and flank wear which was influenced by cutting speed, feed rate, and depth of cut. The Table 4 illustrates the responses of surface roughness, flank wear and cutting force. Analyses were done with ANOVA results for the identifying factors which are affecting the performances.

Table 4. Details of experiments and results

Test No.	C.S A m / min.	DOC B mm	Feed C mm / rev	Surface Roughness Ra -µm	Flank Wear µm
1	225	0.30	0.05	0.44	0.140
2	125	0.30	0.05	0.71	0.180
3	175	0.40	0.04	0.57	0.078
4	175	0.40	0.05	0.49	0.82
5	125	0.40	0.05	1.13	0.090
6	225	0.40	0.05	0.44	0.195
7	225	0.20	0.04	0.90	0.180
8	125	0.30	0.04	1.06	0.120
9	225	0.30	0.04	0.91	0.137
10	125	0.20	0.05	1.08	0.18
11	175	0.30	0.05	0.52	0.15
12	175	0.30	0.04	1.03	0.090
13	125	0.20	0.04	0.41	0.19
14	175	0.20	0.04	0.89	0.17
15	225	0.20	0.05	0.94	0.203
16	125	0.40	0.04	0.50	0.075
17	225	0.40	0.04	0.65	0.02
18	175	0.20	0.05	0.28	0.18

Table 5. ANOVA table for Surface Roughness

	Sum Sq.	DF	Mean Sq.	F Value	Prob> F	Contrn. %
Model	1.06	13	0.082	1.59	0.3503	
A	0.10	2	0.052	1.00	0.4449	7.87
B	0.044	1	0.044	0.85	0.4079	3.47
C	0.074	2	0.037	0.72	0.5401	5.84
AB	0.41	2	0.21	4.02	0.1104	32.33
AC	0.16	4	0.039	0.76	0.6028	12.62
BC	0.27	2	0.14	2.63	0.1863	21.31
Resid ual	0.21	4	0.052			16.56
Cor Total	1.27	17				

The results of surface roughness and flank wear from the ANOVA are shown in the Tables 5 and 6 respectively. The P values in the respective ANOVA tables which are less than 0.10 indicate that it is statistically significant on the performance. The last column of each ANOVA tables indicates the percentage contribution of each source to the total variance indicating the magnitude of influence.

Table.6 ANOVA table for Wear

	Sum Sq.	D. F.	Mean Sq.	F Value	Prob> F	C %
Model	0.39	13	0.030	1.03	0.5434	
A	0.058	2	0.029	1.01	0.4426	11.6
B	0.047	1	0.047	1.64	0.2701	9.40
C	9.743 E-003	2	4.872E-003	0.17	0.8508	0
AB	0.064	2	0.032	1.10	0.4150	12.8
AC	0.16	4	0.039	1.35	0.3890	32.0
BC	0.052	2	0.026	0.90	0.4750	10.2
Residuall	0.12	4	0.029			24.0
Cor Total	0.50	17				

From the table 5 that Cutting speed is contributing to 7.87 % of the variation between feed rate and depth of cut. The second largest is depth of cut 5.84 % which doest not have statistical significance. It may noted that at cutting speed of 225 having 0.40 depth of cut with feed rate of 0.05 lower surface roughness value of 0.44 µm was observed. It is good agreement with other researchers. At 175 cutting speed with 0.20 mm depth of cut having 0.05 mm feed rate lower surface roughness value 0.28 µm and also at 125 cutting speed with 0.20 depth of cut having feed rate of 0.04 mm which has produced surface roughness value of 0.41 µm was obtained. On the tool wear side, a lower flank wear value of 0.02 µm was obtained at high cutting speed of 225 with depth of cut of 0.40 having feed rate of 0.04 mm. The Figure 1 shows the surface roughness and flank wear against the tests.

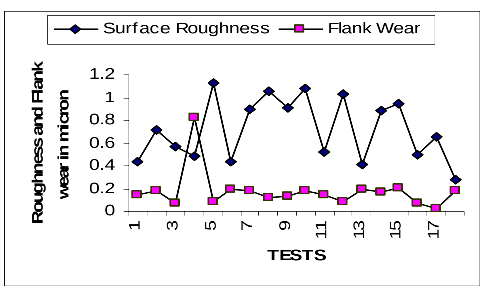

Figure 1. Tests Vs Surface Roughness and flank wear.

C. Mathematical Model

The relation between cutting speed, depth of cut and feed rate was obtained
for surface roughness and flank wear as equations. The respective equations are 1 and 2. These equations give the expected value of the surface roughness and flank wear for combinations of factor levels within the given ranges in the Table 3.

Mathematical equation 1 for surface roughness

$$=0.72+0.096*A[1]-0.089*A[2]-0.049*B+0.031*C[1]+0.059*C[2]+0.21*A[1]B$$
$$-0.15*A[2]B-0.10*A[1]C[1]-0.076*A[2]C[1]+0.011*A[1]C[2]+0.086*A[2]C[2]$$
$$+0.066*BC[1]-0.17$$

Mathematical equation 2 for flank Wear

$$=0.17-0.026*A[1]+0.079*A[2]+0.051*B+0.017*C[1]-0.033*C[2]-0.037*A[1]B$$
$$+0.084*A[2]B+0.036*A[1]C[1]-0.090*A[2]C[1]+0.040*A[1]C[2]-0.095*A[2]C[2]$$
$$-0.045*BC[1]-0.031*BC[2]$$

IX. CONCLUSIONS

The following conclusions were drawn from the Taguchi method of experiments.

1. The study shows that it is an efficient method for determining the optimum operating parameter to achieve lower surface roughness by Taguchi parameter design process.
2. The study found that cutting speed is significant parameter to achieve lowest surface roughness as main effects and interactions between cutting speed - feed rate and cutting speed - depth of cut is significant on surface roughness which contributes 32 % and 13 % of the total variation.
3. The depth of cut has less significant on the roughness.
4. On the flank wear result, cutting speed has significant effect on tool wear. The depth of cut has also have effect on flank wear. It is clear that by reducing the depth of cut, the flank wear can be controlled.
5. The validation tests confirm the above factors.

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