Image processing to measure tool wear for turning AISI 4340 steel using Taguchi method

Prashant D. Kamble
Department of Mechanical Engineering,
Yeshwantrao Chavan College of Engineering
Wanadongri, Nagpur, MS, India

Dr. Atul C. Waghmare
Department of Mechanical Engineering,
Umrer College of Engineering
Umrer, Dist. Nagpur, MS, India

Dr. Ramesh D. Askhedkar
Department of Mechanical Engineering,
KDK College of Engineering
Nagpur, MS, India

Shilpa B. Sahare
Department of Mechanical Engineering,
Yeshwantrao Chavan College of Engineering
Wanadongri, Nagpur, MS, India

***Abstract*—In this paper, an attempt is made to measure the tool wear of single point cutting tool by image processing during turning AISI 4340 steel. Taguchi philosophy is used to design the experiments. L_{27} orthogonal array is used for conducting the experimentation. The input parameters for turning process are Cutting Environment, feed rate, nose radius, depth of cut and tool type. The response variable is tool wear. Consideration of noise factor (uncontrollable factor) makes the design robust. Hence machine tool condition in terms of spindle vibration is involved. Cutting speed is kept constant (210 m/min). MATLAB 13 software is used to measure the wear of tool. A special programme is designed for it. The results of ANOVA for Tool wear indicate that depth of cut is the most significant machining parameters in affecting the tool wear followed by feed rate, nose radius, cutting environment, and tool type. Based on the above discussion and the main effect plot of S/N ratio, the optimal machining parameters are the cutting environment at level 3 (A_3 = MQL), nose radius at level 3 (B_3= 1.2 mm), feed rate at level3 (C_3=0.35 mm/rev), depth of cut at level 1 (D_1 = 0.5 mm), and tool type at level 3 (E_3= coated (CVD)) or $A_3B_3C_3D_1E_3$ in short. Tool wear is optimized up to 0.042 *mm*. Conformity test revealed that the predicted and experimental values of Surface roughness are within the range given by confidence interval.**

Keywords-Image processing, turniing process, Taguchi, ANOVA, noise factor

I. Introduction

Now a day, demand of customers regarding quality of product and its production rate is increasing. To stand in the market with strong root manufactures have to fulfill this demand within the time. This can be achieved by the optimization of the process. Manufacturing process often involves optimization of machining parameters in order to improve product quality as well as to enhance productivity. In metal cutting process, especially turning, milling process, besides the basic cutting process parameters viz. cutting speed, feed rate, depth of cut, tool geometry, environment of cutting and the type of tool plays an important role to decide the performance of quality characteristics.

Hari Singh *et al* [1] (2005), in this paper, a design of experiment based approach is adopted to obtain the optimal setting of turning process parameter that may yield optimum tool wear. The predicted optimal values of flank wear width crater wear depth of coated carbide tool while machining the EN 24 steel are 0.172mm and 0.244 microns respectively.

Shiv Sharma *et al* [2] (2014), this paper stated a Fuzzy logic modeling and multiple performance optimization in turning GFRP composites using desirability function analysis. The input variables are cutting speed, feed rate and depth of cut. The responses are surface roughness, metal removal rate and tool wear. The average percentage error in fuzzy logic prediction obtained as 2.74 %, 12.67 % and 3.06 % for *R*a, *MMR* and *VB* respectively.

Debaprasanna Puhan *et al* [3] (2013), this paper stated hybrid approach for multi-response optimization of non-conventional machining on AlSiCp MMC. The influence of discharge current, pulse duration, duty cycle, and flushing pressure on material removal rate, tool wear rate, surface roughness are studied. It is found that pulse duration, duty cycle, discharge current and flushing pressure contribute significantly to the multiple performance characteristics.

Hari Singh *et al* [4] (2003), Araştırma Makalesi *et al* [5] (2006), Nilrudra Mandal *et al* [18] (2011), these paper stated the effect of cutting speed, feed rate, depth of cut on flank wear, crater wear, tool wear during turning of EN24 steel, AISI 304 Austenite stainless steel, AISI 4340 steel respectively.

Mr. Ballal Yuvaraj *et al* [6] (2012), this paper used 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.

II. TAGUCHI PHILOSOPHY

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. It is a simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost.
b. It helps 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. It includes the noise factor and makes the design robust.

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

A quality characteristic is the object of interest of a product or a process. It is called as a functional characteristic.

Generally, the quality characteristic has a target.

There are three types of targets:

1. ***Lower the better (LB) –***
It is a non-negative measurable characteristic that has an ideal state or target of zero.

$$S/N = -10\log\left(\left(\frac{1}{n}\right)\sum y^2\right) \quad (1)$$

2. ***Nominal the best (NB) –***
It is a measurable characteristic with a specific user defined target value.

$$S/N = -10\log\left(\frac{\hat{y}}{s^2}y\right) \quad (2)$$

3. ***Larger the better (LB)*** –
It is a non-negative measurable characteristic that has an ideal state or target of infinity.

$$S/N = -10\log\left(\left(\frac{1}{n}\right)\sum\frac{1}{y^2}\right) \quad (3)$$

III. EXPERIMENTATION

The experiment was performed on CNC SPINNER15 lathe machine as shown in fig 1. Test pieces of size 50mm×80mm were cut from EN 24 steel bar. The five input variables used in this study are cutting environment, Nose radius, Feed rate, Depth of cut and tool type and spindle vibration was taken as a noise factor. Cutting speed was kept constant.

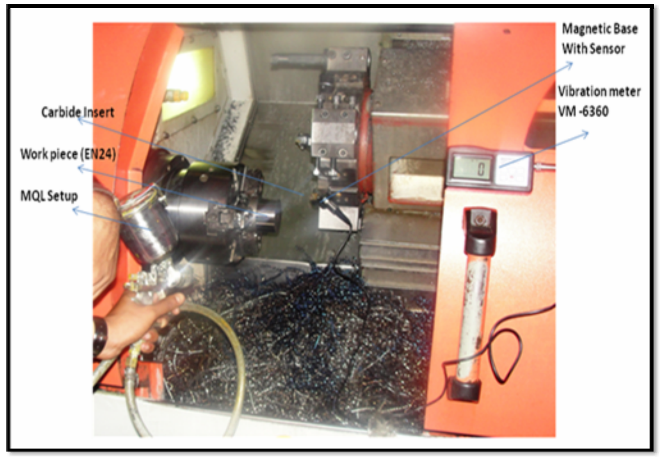

FIGURE 1 EXPERIMENTAL SETUP

FIGURE 2 CNC LATHE SPINNER

TABLE 1PROCESS PARAMETERS AND THEIR LEVELS

Process Parameters	Level-1	Level-2	Level-3
Cutting Environment (A)	Dry	Wet	MQL
Nose radius (mm) (B)	0.4	0.8	1.2
Feed rate (m/rev) (C)	0.15	0.25	0.35
Dept of cut (mm) (D)	0.5	1	1.5
Tool type (E)	Uncoated	PVD	CVD
Spindle vibration (m/s^2) (NF)	1.7	4.3	6.9

A. *Measurement of Surface Roughness*

Cutting tool wear is measured by the image processing method in MATLAB software. This is a non conventional method used for edge detection of tool. A special algorithm is made to detect the edge of the tool as shown below

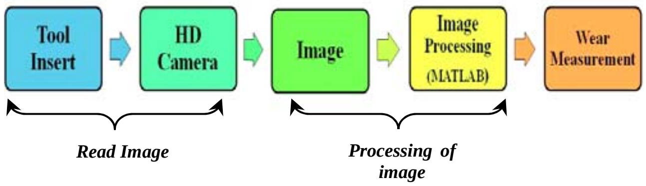

FIGURE 3 FLOW CHART OF TOOL WEAR MEASUREMENT

A. *Steps of Wear Measurement*

(1.) Read the image:

The tool wear image is captured by high definition CCD camera and is fed to the image processing in MATLAB software as an input.

(2.) Processing of image:

If the quality of the image is not good and clear, may be due to poor illumination, the image needs pre-processing. It involves making background uniform and adjusting contrast ie image enhancement. To enhance the good quality of the image, a self developed shadow removing algorithm written in MATLAB and the Canny edge detection algorithm in digital image processing toolbox for MATLAB was used for the segmentation of the wear area in the captured image. The Canny edge detection algorithm was preferred over other edge detection methods because of its double thresholds feature that allows detection of both strong and weak edges. The detected weak edges are included in the output only if they are connected to strong edges. The captured image is then saved in ‘jpeg’ format for further processing. Wear detection: edge detection technique is used for wear measurement. There are various methods used for edge detection like Sobel, Prewitt, Robert; and Canny. Out of these methods, Canny is used as it gives the best performance. It also removes the noise present in the image.

(3.) Wear measurement:

Wear measurement is done in terms of flank wear by using flank wear conditions. A new tool wear measurement technology is proposed and developed by image processing method. Software in MATLAB environment is developed to verify the suggested image. This method can extract the wear area based on a 2D image process algorithm. This method is not able to estimate the depth of tool wear region.

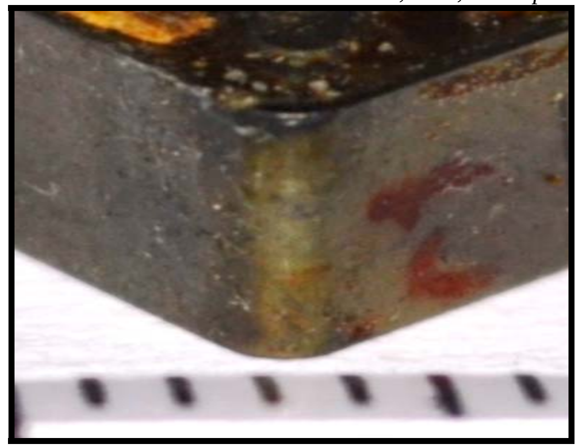

FIGURE 4 ACTUAL IMAGE OF TOOL

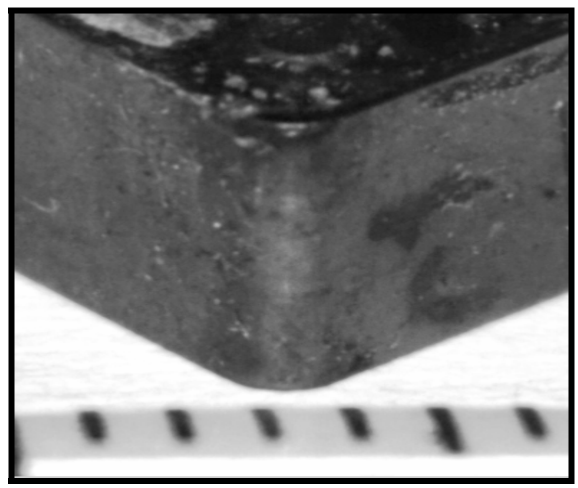

FIGURE 5 GREY SCALE IMAGE OF TOOL

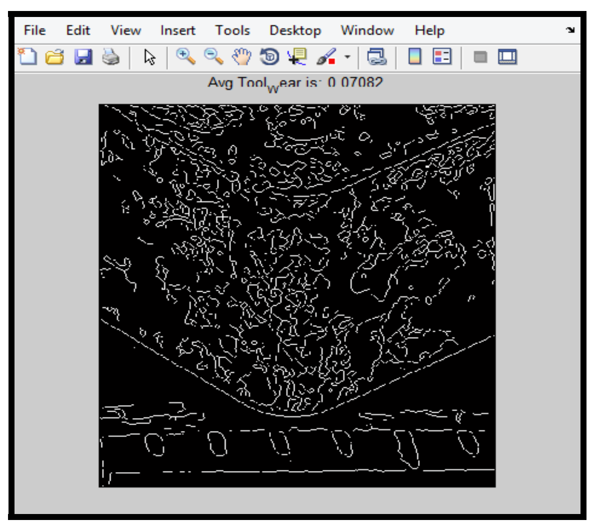

FIGURE 6 TOOL WEAR MEASUREMENT BY EDGE DETECTION TECHNIQUE

TABLE 2 EXPERIMENTAL DATA FOR TOOL WEAR AT THREE LEVELS OF SPINDLE VIBRATION

Run	Tool Wear_NF_1	Tool Wear_NF_2	Tool Wear_NF_3	Average Tool Wear
1	0.124	0.125	0.195	0.148
2	0.087	0.087	0.136	0.103
3	0.130	0.131	0.204	0.155
4	0.102	0.102	0.160	0.121
5	0.140	0.141	0.220	0.167
6	0.060	0.060	0.094	0.071
7	0.145	0.146	0.228	0.173
8	0.051	0.052	0.081	0.061
9	0.066	0.066	0.103	0.078
10	0.142	0.143	0.223	0.169
11	0.104	0.105	0.163	0.124
12	0.147	0.148	0.231	0.175
13	0.119	0.120	0.187	0.142
14	0.158	0.158	0.247	0.188
15	0.078	0.078	0.122	0.093
16	0.163	0.164	0.256	0.195
17	0.069	0.069	0.108	0.082
18	0.083	0.084	0.130	0.099
19	0.114	0.114	0.178	0.136
20	0.076	0.077	0.119	0.091
21	0.119	0.120	0.187	0.142
22	0.091	0.092	0.143	0.109
23	0.129	0.130	0.203	0.154
24	0.049	0.050	0.078	0.059
25	0.135	0.136	0.212	0.161
26	0.041	0.042	0.065	0.049
27	0.055	0.056	0.087	0.066

The experiments are conducted as per Taguchi method and experimental data is collected for tool wear. Tool wear is measured for each level of spindle vibration and average value is taken as the final value shown in table.

IV. DATA ANALYSIS

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

1. Selection of equation for Signal-to-Noise ratio (S/N ratio) according to the objective of optimization. As the objective is to minimize the tool wear, therefore lower the better (LB) equation (1) has been selected for S/N ratio.
2. Computation of S/N ratio for each run. Tool wear with S/N ratio is listed in table 3.
3. Calculations of response table for mean S/N ratio at each level of tool wear to identify the rank of level table 4 & fig 7
4. Selection of optimal setting from mean S/N ratio.
5. Computations of ANOVA to find the significance and contribution of each parameter on the tool wear.
6. Calculation of predicted value of tool wear by predicted additive model.
7. Verification of predictive model by confirmatory test.

TABLE 3 TOOL WEAR AND SIGNAL TO NOISE RATIO

Run	Average Tool Wear	SN ratio Tool Wear
1	0.148	16.5912
2	0.103	19.7259
3	0.155	16.2009
4	0.121	18.3176
5	0.167	15.5590
6	0.071	22.9192
7	0.173	15.2281
8	0.061	24.2507
9	0.078	22.1032
10	0.169	15.4207
11	0.124	18.1235
12	0.175	15.1231
13	0.142	16.9645
14	0.188	14.5329
15	0.093	20.6475
16	0.195	14.2181
17	0.082	21.7015
18	0.099	20.0913
19	0.136	17.3603
20	0.091	20.8517
21	0.142	16.9347
22	0.109	19.2653
23	0.154	16.2385
24	0.059	24.5961
25	0.161	15.8569
26	0.049	26.1409
27	0.066	23.6159

A. *Mean S/N ratio for Tool wear*

The mean S/N ratio for each input parameter at levels 1, 2, and 3 is calculated by averaging the S/N ratios at respective level. Fig. 7 shows the S/N response graph for tool wear. The Mean S/N ratio is used to find out optimal level for each parameter and rank of the parameter.

TABLE 4 RESPONSE TABLE FOR SIGNAL TO NOISE RATIO

Level	Cutting environment	Nose radius	Feed rate	Depth of cut	Tool type
1	-13.552	-14.612	-15.293	-11.651	-11.197
2	-11.860	-12.014	-12.620	-11.282	-11.926
3	-10.348	-9.134	-7.847	-12.827	-12.636
Delta	3.204	5.477	7.446	1.546	1.439
Rank	*3*	*2*	*1*	*4*	*5*

TABLE 5 ANALYSIS OF VARIANCE FOR S/N

Process parameters	DOF	SOS	MSOS	F	P	% Contribution
Cutting environment (A)	2	0.005111	0.002556	8.49	0.000	10.05
Nose radius (B)	2	0.004304	0.002152	7.15	0.000	8.46
Feed rate (C)	2	0.010758	0.005379	17.87	0.000	21.16
Depth of cut (D)	2	0.027686	0.013843	45.99	0.000	54.45
Tool type (E)	2	0.001754	0.000877	2.91	0.000	3.45
*A * B*	4	0.000011	0.000003	0.01	0.828	0.02
*A * C*	4	0.000009	0.000002	0.01	0.926	0.02
*A * D*	4	0.000012	0.000003	0.01	0.640	0.02
Residual Error	4	0.001204	0.000301			2.37
Total	*26*	*0.050849*				100.00

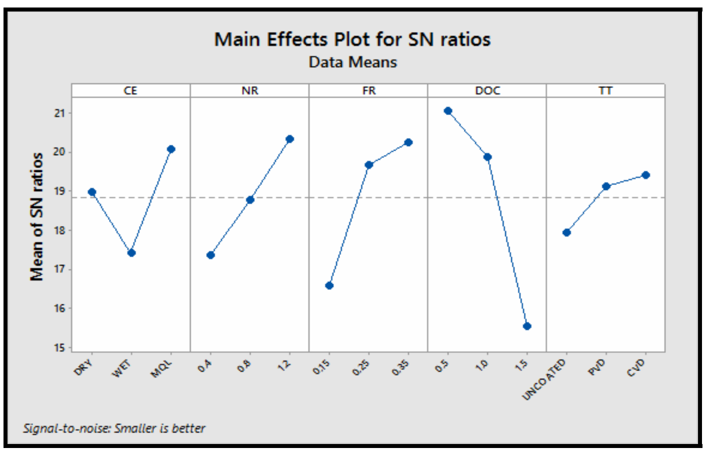

FIGURE 7 MAIN EFFECT PLOT OF SIGNAL TO NOSE RATIO

B. *Predicted Value of Tool wear (mm)*

Optimal value of output parameter can be predicted by additive model

$$\mu_{pred} = \bar{Y} + \sum(\bar{Y}_i - \bar{Y}) \qquad (4)$$

µTW = YTW + (A3 - YTW) + (B3- YTW) + (C3 - YTW) + (D1 - YTW) + (E3 - YTW)

µTW = 0.123 + (0.107-0.123) + (0.107- 0.123) + (0.104-0.123)+ (0.097-0.123) + (0.115- 0.123) = 0.0401 mm

Error variance Ve=0.000301

Therefore,

CI= + - 0.018

The 95% confidence interval of the population is: [µTW− CI] < µTW < [µTW+ CI]

0.0223< 0.0401 < 0.0579

TABLE 6 CONFIRMATORY EXPERIMENTS FOR TOOL WEAR (MM).

Sample	Tool Wear (mm) NF1 1.7 m/s²	NF2 4.3 m/s²	NF3 6.9 m/s²
1	0.0338	0.0346	0.0588
2	0.0339	0.0368	0.0549
3	0.0342	0.0357	0.0568
Average	0.0340	0.0357	0.0568
Total Average	0.0422		

V. RESULTS

The results of ANOVA for Tool wear indicate that depth of cut is the most significant machining parameters in affecting the tool wear followed by feed rate, nose radius, cutting environment, and tool type. Based on the above discussion and the main effect plot of S/N ratio, the optimal machining parameters are the cutting environment at level 3 (A_3 = MQL), nose radius at level 3 (B_3= 1.2 mm), feed rate at level3 (C_3=0.35 mm/rev), depth of cut at level 1 (D_1 = 0.5 mm), and tool type at level 3 (E_3= coated (CVD)) or $A_3B_3C_3D_1E_3$ in short

TABLE 7 VALUES OF PROCESS PARAMETERS AT OPTIMUM LEVEL

Process Parameters	Code	level1	level2	level3
Cutting Environment	A	DRY	WET	MQL
Nose radius(mm)	B	0.4	0.8	1.2
Feed rate (mm/rev)	C	0.15	0.25	0.35
Dept of cut (mm)	D	0.5	1	1.5
Tool type	E	Uncoated	PVD	CVD

VI. CONCLUSION

The Taguchi method is successfully applied in this study to find optimal setting for turning AISI 4340 steel. The results are discussed as follows:

(1) The single-objective problem is solved with the application of Taguchi Analysis.
(2) Quality characteristic Tool Wear is optimized to 0.042 mm
(3) Optimal parameter setting for turning AISI 4340 steel is (A_3 B_3 C_3 $D_1$and E_3) i.e. cutting environment=MQL,

nose radius=1.2 mm, feed rate =0.35 mm/rev, depth of cut = 1.5 mm, and PVD coated cutting tool.

(4) Conformity test shows that the predicted and experimental values of Tool Wear are within the range given by confidence interval.

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AUTHORS PROFILE

Prashant D. Kamble received his M.Tech degree in CAD/CAM Branch of Mechanical Engineering from YCCE, Nagpur in 2006 year and submitted PhD thesis in Mechanical Engineering from RTMNU, Nagpur University. Presently he is working as Asst Prof./ Professor in Department of Mechanical Engineering in YCCE, Nagpur. His paper publication details are: International Conference:-18, International Journals:- 22