# OPTIMIZATION OF TOOL WEAR IN HARD TURNING OF EN 24 STEEL USING DoE AND VERIFICATION THROUGH ANOVA AND RSM

G. Ragul[1], Dr. S. Sankar[2]
[1]*PG Scholar, Department of Mechanical Engineering,*
[2]*Associate Professor, Department of Mechanical Engineering,*
*Nehru College of Engineering and Research Centre, Kerala.*

***Abstract-*** **This paper describes prediction of tool wear in hard turning of 817M40 (EN 24) steel material with 48 HRC at conventional lathe using Multicoated hard metal inserts with sculptured rake face geometry. Also, an attempt was made to fuse cutting force, cutting temperature and tool vibration (displacement), along with cutting velocity, feed and depth of cut to predict tool wear. In this work, based on Taguchi $L_{18}$ orthogonal array (mixed design) using Minitab software was used to optimize the various cutting parameters such as cutting velocity, feed and depth of cut. In addition, the results obtained from Design of Experiment are compared with Analysis of Variance (ANOVA) Response surface methodology (RSM). The result obtained from Response surface methodology (RSM) and Analysis of Variance (ANOVA) confirms very closely with the result given by Design of Experiment (DoE).**

***Index Terms-*** **Tool Wear, Hard Turning, Minitab, Response Surface methodology, Analysis of Variance.**

## I. INTRODUCTION

The concept of hard turning has gained considerable attention in metal cutting as it can apparently replace the traditional process cycle of turning, heat treating and finish grinding for assembly of hard wear resistant steel parts. Hard turning can possibly facilitate low process cost, low process time, better surface quality and lower waste. In hard turning, tool wear becomes an important parameter affecting the surface quality of finished parts. Turning is a common machining process used especially for the finishing of components. In machining, tool wear is a natural phenomenon that refers to the cutting tool gradually losing its cutting ability, progressively leading to tool failure. Tool wear is definitely unpleasant because as it increases to a certain value, the tool needs to be changed. Replacement with a new tool results in process interruption and rising machining cost, which is the most undesirable consequence in the manufacturing field. Therefore, to achieve high quality machining performance, machining parameter selection and control are essential. Tool wear is a highly complex phenomenon which can lead to machine downtime, product rejects and can also cause problems to person. High cutting force, excessive cutting temperature and increase in tool vibration are indications of progressing tool wear. In other words, cutting force, cutting temperature and vibration signals can be considered as symptoms of tool wear and these symptoms can be analyzed individually and collectively to predict tool wear. It is possible to predict tool wear by considering the symptoms individually. However a more accurate prediction is possible by considering cutting force, cutting temperature and displacement of tool vibration signals along with input parameters like cutting velocity, feed rate and depth of cut collectively. In the present study, tool wear symptoms are considered collectively, leading to a more accurate prediction of tool wear than is possible considered individually. Here an attempt was fuse the operating parameters along with cutting force, cutting temperature, displacement of tool vibration using Response Surface methodology during turning of hardened EN 24 steel.

### A. SELECTION OF WORK MATERIAL

The work piece material was EN24 steel which was hardened to 48 HRC by heat treatment and dimensions are given in fig 1. EN24 steel is taken as work piece due to wide range of applications in aircraft, automotive and general engineering applications as propeller or gear shafts, connecting rods, aircraft landing gear components.


Fig 1: Work piece Dimensions

*B.* SELECTION OF CUTTING TOOL AND TOOL HOLDER

The tool holder used had the specification PSBNR 2525 M12. Multicoated hard metal inserts with sculptured rake face geometry, having the specification SNMG 120408 from M/S Taegu Tec India (P) Ltd, were used as cutting tools in this investigation.

C. PROPERTIES OF MATERIAL

Table 1: Composition of EN24 Steel

| Chemical Composition (%) | |
|---|---|
| Carbon | 0.38 - 0.44 |
| Chromium | 1.0 – 1.44 |
| Iron | Balance |
| Manganese | 0.45 - 0.70 |
| Molybdenum | 1.30 – 1.70 |
| Nickel | 1.65 – 2 |
| Phosphorus | 0.040 max |
| Silicon | 0.10 - 0.35 |
| Sulphur | 0.04 max |

## II. EXPERIMENTAL SETUP

In this hard turning operation were carried out on a Kirloskar Turn master-35 lathe. A photograph of the setup used for present investigation is shown in fig 2. The main cutting force, cutting temperature, tool wear were measured during each experiment. The main cutting force was measured using kistler force dynamometer. The flank wear was measured by tool makers microscope by moving cross wires to appropriate locations and temperature was measured by Infra Red Thermometer. Similarly, tool vibrations also measured by piezoelectic digital vibrometer.

Fig 2: Photograph of Experimental Setup

## III. DESIGN OF EXPERIMENTS

A 18-run experiment was designed based on Taguchi technique in which the input variables such as cutting velocity (50, 60), feed (0.05, 0.06, 0.07), depth of cut (0.3, 0.4, 0.5) were varied at three levels(Mixed design) using Minitab software. In this study, experiment work was carried out in dry turning. Cutting velocity, feed, depth of cut were varied at three levels (Low, Medium and High) as shown in Table 2. Three inserts were used in these experiments and the data collected were shown in table 3.

Table 2: Selected Factors and their Levels

| Variables | | |
|---|---|---|
| Cutting velocity($V_c$) (m/min) | Depth of cut (d) (mm) | Feed rate (f) (mm/rev) |
| | Level 1 | Level 1 |
| Level 1 | Level 2 | Level 2 |
| Level 2 | Level 3 | Level 3 |

Table 3: Data collected during 18-run experiment

| S.No | $V_c$(m/min) | d(mm) | f(mm/rev) | $F_C$(N) | $T_C$($^0$C) | $V_b$(mm) |
|---|---|---|---|---|---|---|
| 1 | 60 | 0.3 | 0.05 | 157.7 | 62.26 | 0.06 |
| 2 | 60 | 0.3 | 0.06 | 259.0 | 51.35 | 0.04 |
| 3 | 60 | 0.3 | 0.07 | 191.4 | 54.53 | 0.06 |
| 4 | 60 | 0.4 | 0.05 | 149.4 | 53.64 | 0.07 |
| 5 | 60 | 0.4 | 0.06 | 180.7 | 52.43 | 0.08 |
| 6 | 60 | 0.4 | 0.07 | 186.7 | 56.76 | 0.108 |
| 7 | 60 | 0.5 | 0.05 | 516.6 | 61.56 | 0.086 |
| 8 | 60 | 0.5 | 0.06 | 134.0 | 57.87 | 0.089 |
| 9 | 60 | 0.5 | 0.07 | 186.7 | 64.6 | 0.103 |
| 10 | 70 | 0.3 | 0.05 | 170.7 | 61.4 | 0.105 |
| 11 | 70 | 0.3 | 0.06 | 302.1 | 64.8 | 0.102 |
| 12 | 70 | 0.3 | 0.07 | 201.5 | 63.5 | 0.105 |
| 13 | 70 | 0.4 | 0.05 | 101.6 | 67.4 | 0.106 |
| 14 | 70 | 0.4 | 0.06 | 130.2 | 61.2 | 0.095 |
| 15 | 70 | 0.4 | 0.07 | 256.7 | 65.4 | 0.134 |
| 16 | 70 | 0.5 | 0.05 | 348.0 | 71.3 | 0.157 |
| 17 | 70 | 0.5 | 0.06 | 137.7 | 68.4 | 0.196 |
| 18 | 70 | 0.5 | 0.07 | 191.7 | 70.3 | 0.182 |

## IV. RESULTS AND DISCUSSION

The reading for 18-run experiment was obtained in the experimentation phase is analyzed by using ANOVA table and it is then verified by Minitab software. The analysis of the results was done by using MINITAB 16 statistical software for finding the optimized value on tool wear.

### A. TOOL WEAR

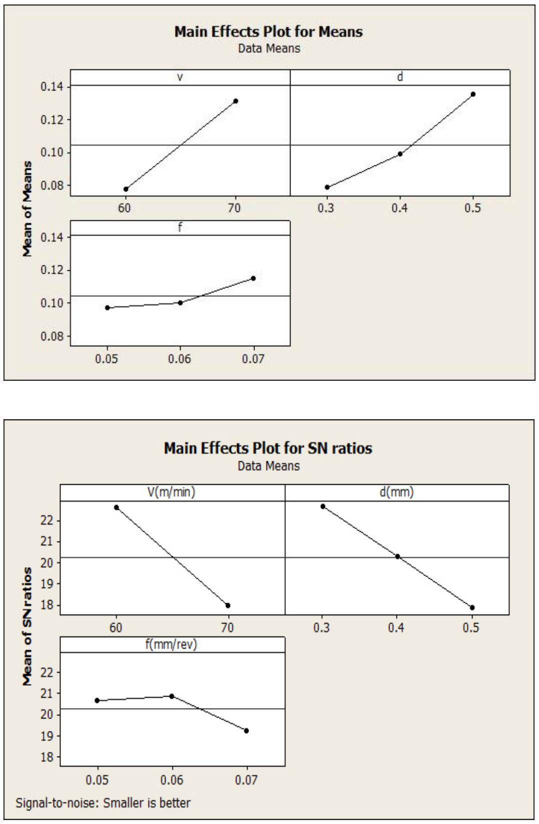



Fig 3: Graph showing Tool wear at each level

Table 4: Response Table for Means

| Level | v | D | F |
|---|---|---|---|
| 1 | 0.07733 | 0.7867 | 0.09733 |
| 2 | 0.11883 | 0.11883 | 0.12033 |
| 3 | | 0.13550 | 0.11533 |
| Delta | 0.0415 | 0.05683 | 0.01800 |
| Rank | 2 | 1 | 3 |

Smaller is better

Table 5: Response Table for Signal to Noise (S/N) Ratios

| Level | V | D | F |
|---|---|---|---|
| 1 | 22.59 | 22.64 | 20.67 |
| 2 | 17.93 | 21.29 | 21.89 |
| 3 | | 17.85 | 19.22 |
| Delta | 4.65 | 4.79 | 1.67 |
| Rank | 2 | 1 | 3 |

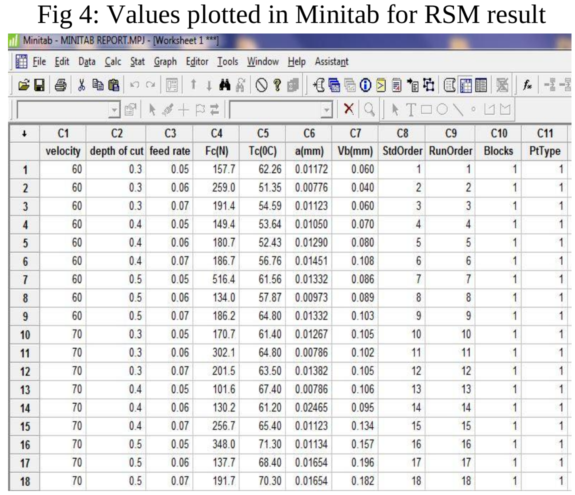
Table 6: Analysis of Variance for Means

| Source | Seq SS | Adj SS | AdjMS | F | P (%) |
|---|---|---|---|---|---|
| $V_C$ | 0.01312 | 0.01312 | 0.0131 | * | 34.81 |
| d | 0.00996 | 0.00996 | 0.0049 | * | 55.86 |
| f | 0.00111 | 0.00111 | 0.0005 | * | 3.91 |
| Total | 0.02422 | - | - | * | 5.42 |

Table 7: Analysis of Variance for S/N ratios

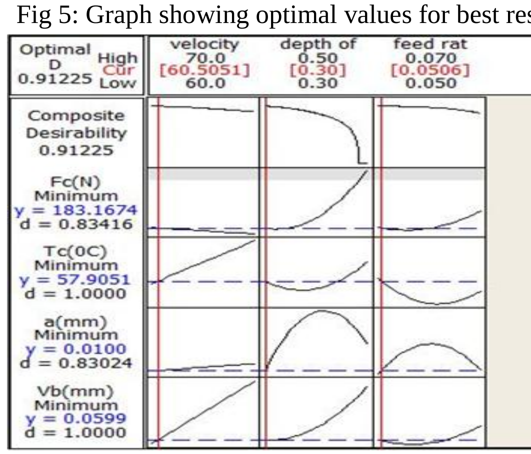
| Source | Seq SS | Adj SS | Adj MS | F | P(%) |
|---|---|---|---|---|---|
| $V_C$ | 97.314 | 97.314 | 97.314 | * | 34.01 |
| d | 68.710 | 68.710 | 34.355 | * | 58.17 |
| F | 9.807 | 9.807 | 4.904 | * | 4.85 |
| Total | 175.831 | - | - | * | 2.97 |

Fig 4: Values plotted in Minitab for RSM result




| ↓ | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | velocity | depth of cut | feed rate | Fc(N) | Tc(0C) | a(mm) | Vb(mm) | StdOrder | RunOrder | Blocks | PtType |
| 1 | 60 | 0.3 | 0.05 | 157.7 | 62.26 | 0.01172 | 0.060 | 1 | 1 | 1 | 1 |
| 2 | 60 | 0.3 | 0.06 | 259.0 | 51.35 | 0.00776 | 0.040 | 2 | 2 | 1 | 1 |
| 3 | 60 | 0.3 | 0.07 | 191.4 | 54.59 | 0.01123 | 0.060 | 3 | 3 | 1 | 1 |
| 4 | 60 | 0.4 | 0.05 | 149.4 | 53.64 | 0.01050 | 0.070 | 4 | 4 | 1 | 1 |
| 5 | 60 | 0.4 | 0.06 | 180.7 | 52.43 | 0.01290 | 0.080 | 5 | 5 | 1 | 1 |
| 6 | 60 | 0.4 | 0.07 | 186.7 | 56.76 | 0.01451 | 0.108 | 6 | 6 | 1 | 1 |
| 7 | 60 | 0.5 | 0.05 | 516.4 | 61.56 | 0.01332 | 0.086 | 7 | 7 | 1 | 1 |
| 8 | 60 | 0.5 | 0.06 | 134.0 | 57.87 | 0.00973 | 0.089 | 8 | 8 | 1 | 1 |
| 9 | 60 | 0.5 | 0.07 | 186.2 | 64.80 | 0.01332 | 0.103 | 9 | 9 | 1 | 1 |
| 10 | 70 | 0.3 | 0.05 | 170.7 | 61.40 | 0.01267 | 0.105 | 10 | 10 | 1 | 1 |
| 11 | 70 | 0.3 | 0.06 | 302.1 | 64.80 | 0.00786 | 0.102 | 11 | 11 | 1 | 1 |
| 12 | 70 | 0.3 | 0.07 | 201.5 | 63.50 | 0.01382 | 0.105 | 12 | 12 | 1 | 1 |
| 13 | 70 | 0.4 | 0.05 | 101.6 | 67.40 | 0.00786 | 0.106 | 13 | 13 | 1 | 1 |
| 14 | 70 | 0.4 | 0.06 | 130.2 | 61.20 | 0.02465 | 0.095 | 14 | 14 | 1 | 1 |
| 15 | 70 | 0.4 | 0.07 | 256.7 | 65.40 | 0.01123 | 0.134 | 15 | 15 | 1 | 1 |
| 16 | 70 | 0.5 | 0.05 | 348.0 | 71.30 | 0.01134 | 0.157 | 16 | 16 | 1 | 1 |
| 17 | 70 | 0.5 | 0.06 | 137.7 | 68.40 | 0.01654 | 0.196 | 17 | 17 | 1 | 1 |
| 18 | 70 | 0.5 | 0.07 | 191.7 | 70.30 | 0.01654 | 0.182 | 18 | 18 | 1 | 1 |

Fig 5: Graph showing optimal values for best result




From the graph it is seen that the RSM predicted values for best cutting performance is that the velocity should be kept at 60 m/mm, feed at 0.05 mm/rev and depth of cut at 0.3 mm. The predicted values obtained from software is again checked for the actual values by conducting a cutting experiment by keeping the above values constant and the results were plotted. Fig 5 shows the tabulation for RSM prediction of the input values. In this method all the output variables are compared along with all input variables and best input values are chosen for keeping tool vibration, cutting force and tool wear to minimum. The results obtained from the confirmatory experiment conducted RSM predicted input values are shown in table 9.

Table 8: Optimized of V, d, f by Response Surface Methodology (RSM)

| Parameters | Starting value | Optimized response |
|---|---|---|
| $V_C$ | 60 | 60.50 |
| D | 0.3 | 0.3 |
| F | 0.05 | 0.050 |

%error = (1-predicted value/actual value)* 100

Table 9: Percentage error between predicted and actual value

| Predicted Response | Predicted Value | Actual Value | % Error |
|---|---|---|---|
| $F_C$(N) | 183.167 | 189.85 | 3.52 |
| $T_C$($^0$C) | 57.905 | 61.02 | 5.10 |
| a(mm) | 0.01000 | 0.01013 | 0.99 |
| $V_b$(mm) | 0.060 | 0.062 | 3.22 |

Table 10: Optimized parameters for the Minimum Tool Wear by Experiment

| Parameters | DoE | RSM | ANOVA Priority (%) |
|---|---|---|---|
| $V_C$ | 60 | 60.50 | 34.81 |
| D | 0.3 | 0.30 | 55.86 |
| F | 0.05 | 0.05 | 3.91 |

## V. CONCLUSION

It is evident from table 10 shows that the optimal parameter for minimum Tool Wear through DoE is 60 m/min ($V_C$), 0.05mm/rev (f), 0.3mm (d). Similarly the optimized parameter from RSM is 60.50m/min ($V_C$), 0.0505mm/rev (f), 0.3mm (d). It is observed that the result obtained from RSM is closely matching with the result obtained from DoE (Taguchi technique). In addition a comparison was made in Analysis of Variance (ANOVA) to confirm the above parameters. It is evident from ANOVA result that the Depth of cut (55%) and Cutting velocity (34%) are the critical parameter which contributes for minimum Cutting Tool Wear.

## APPENDIX

| | |
|---|---|
| $V_C$ | Cutting velocity m/min |
| F | Feed in mm/rev |
| D | Depth of cut in mm |
| $F_C$ | Cutting force in Newton |
| $T_C$ | Cutting temperature in $^0$C |
| $V_b$ | Average Flank wear in mm |

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