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Investigation and Optimization of Tool Tip Temperature in Turning of OHNS

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Abstract: Optimum performance in a turning operation is governed by selecting desired machining parameters. Selection of desired machining parameters by experience or using handbook does not ensure that the selected machining parameters are optimal for a particular machine or environment. The effect of machining parameters is reflected on temperatures developed in machining. These temperatures developed in machining play an important role in tool wear which results in poor surface finish and can also result in modifications to the properties of workpieces and tool materials. As there is general tendency for dry machining due to environmental reasons, cost considerations etc. It is important to understand how temperatures are affected by the process variables i.e. spindle speed, feed and depth of cut.

This paper reviews the machining parameters affecting the performance of turning such as spindle speed, feed and depth of cut.

Keywords: spindle speed, feed, depth of cut, tool tip temperature etc.

I. INTRODUCTION

Turning operation using a single point cutting tool has been one of the oldest and popular methods of metal machining. It has even replaced grinding in several applications with reduced lead time without affecting the surface quality [1]. The achievement of high quality, in terms of workpiece dimensional accuracy, surface finish, high production rate, less wear on cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact are the main effective challenges of modern metal machining and machining industries [2]. CBN tools are widely used in the metal-working industry for machining various hard materials such as high spindle speed tool steels, die steels, bearing steels, case-hardened steels, white cast iron and alloy cast irons. In many applications, machining of ferrous materials in their hardened condition can replace grinding to give significant savings in cost and productivity rates [3]. The aim of machining is to manufacture product with less cost of high dimensional accuracy and surface finish. At the same time, machining operations should be targeted towards dry or near dry machining to avoid environmental problems associated with the use of machining fluids. To cope up with above situations, now-a-days 80% of all machining operations are performed with coated carbide cutting tools [4].

The aim of presented work is to investigate and optimize the machining parameters affecting the performance of turning such as spindle speed, feed and depth of cut.

II. TURNING PROCESS

Turning is a form of machining or a material removal process which is used to create rotational parts by removing unwanted material as shown in Fig. 1. The turning process is associated with the workpiece and cutting tool. The workpiece is a piece of re-shaped material that is secured to the fixture, which itself is attached to the turning machine and allowed to rotate at high spindle speeds. The cutter is typically a coated carbide cutting tool that is also secured in the machine. The cutting tool feed rates into the rotating workpiece and cuts away material in the form of small chips to create the desired shape.

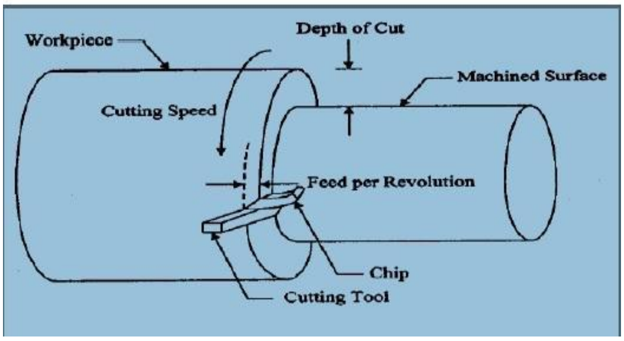


Fig.1: The Turning Process

In turning process, the machining parameters like spindle speed, feed rate, depth of cut are selected for each operation based upon the workpiece material, tool material, tool size etc. The machining parameters that influence the turning process are spindle speed, feed rate, depth of cut, tool temperature, insert geometry etc. [5]. The properties of work material control the chip formation. The work material properties include yield strength, shear strength, shear strength under compressive loading, strain hardening, friction behavior, hardness and ductility. The highly ductile work material not only permit extensive deformation of chip during cutting but also increases work heat generation and temperature which results in longer continuous chip. The machining parameters like spindle speed, feed rate and depth of cut also influence chip formation. Other machining parameters like tool material, tool angle, edge geometry which changes due to wear, while the cutting environment like as machine tool deflection, cutting fluid also responsible in cutting mechanism. In machining, the resultant force which consists of frictional force and normal force acting on shear plane area is mathematically calculated for given material. Some researchers are attempting to predict shear force and shear direction from dislocation theory but this has not yet been accomplished. The cutting force is the dominant force in the system and it is important to understand how it varies with changes in machining parameters. The cutting force is typically doubled when the feed rate or depth of cut is doubled but remains constant when spindle speed is increased. [6]

III. LITERATURE REVIEW

Anand S. Shivade et al. [7] discussed an investigation into the use of Taguchi parameter design to optimize the tool tip temperature in turning operation using single point carbide cutting tool on EN-8 steel. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. The author concluded that for tool tip temperature optimum combination was A1B1 which gives the best results. Satyanarayana Kosaraju et al. [8] focused on investigating the effect of process parameters on machinability performance characteristics and there by optimization of the turning of Titanium (Grade 5) based on Taguchi method. The cutting spindle speed, feed rate and depth of cut were used as the process parameters where as the temperature was selected as performance characteristic. The L9 orthogonal array based on design of experiments was used to conduct experiments. The degree of influence of each process parameter on individual performance characteristic was analyzed from the experimental results obtained using Taguchi Method. The cutting spindle speed was identified as the most influential process parameter on temperature. Trajcevski N. et al. [9] presented the results and obtained mathematical models of temperature during machining process by high spindle speed turning as a function of processing parameters like cutting spindle speed, feed rate, depth of cut and nose radius. The authors concluded that the average cutting temperature mostly depends upon cutting spindle speed and feed rate, while it is least dependent upon depth of cut. The increase of these parameters causes average temperature increase, which reached highest value of 1043^0 C in the investigated domain. L.B.ABHANG and M. HAMEEDULLAH [10] measured experimentally the tool-chip interface temperature during turning of EN-31 steel alloy with tungsten carbide inserts using a tool-work thermocouple technique. First and second order mathematical models are developed in terms of machining parameters by using the response surface methodology on the basis of the experimental results. The results are analyzed statistically and graphically. The metal cutting parameters considered are cutting spindle speed, feed rate, depth of cut and tool nose radius. It can be seen from the first order model that the cutting spindle speed, feed rate and depth of cut are the most significantly influencing parameters for the chip-tool interface temperature followed by tool nose radius. Another quadratic model shows the variation of chip-tool interface with major interaction effect between cutting spindle speed and depth of cut; second order (quadratic) effect of cutting spindle speed (V^2) appears to be highly significant. The results show that increase in cutting spindle speed, feed rate and depth of cut increases the cutting temperature while increasing nose radius reduces the cutting temperature. The suggested models of chip-tool interface temperature adequately map within the range of the cutting conditions considered. A. V. DHOTE et al. [11] studied experimentally the influence of depth of cut, cutting spindle speed, cutting angle, feed rate, tool rake angle and work piece material type on the tool tip temperature during a turning process. The experiments were obtained by varying one parameter while, the remaining three parameter were kept constant. To increase the tool life, optimization of machining parameters using Taguchi optimization method is done. In this study, the Taguchi method, a powerful tool of design optimization for quality, is used to find the optimal cutting parameters for turning operations. Through this study, not only the optimal cutting parameters for turning operations are obtained, but also the main cutting parameters that affect the cutting performance in turning operations were evaluated. Experimental results are provided to confirm the effectiveness of this approach.

IV. EXPERIMENTAL DETAILS

In this study, Taguchi method is used for single characteristics optimization in order to establish a correlation between the input and output variables. Therefore, the experiments were performed according to a Taguchi design of experiments.

A. Taguchi Method

Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The greatest advantage of this method is to save the effort in performing experiments: to save the experimental time, to reduce the cost and to find out significant factors fast. [12]

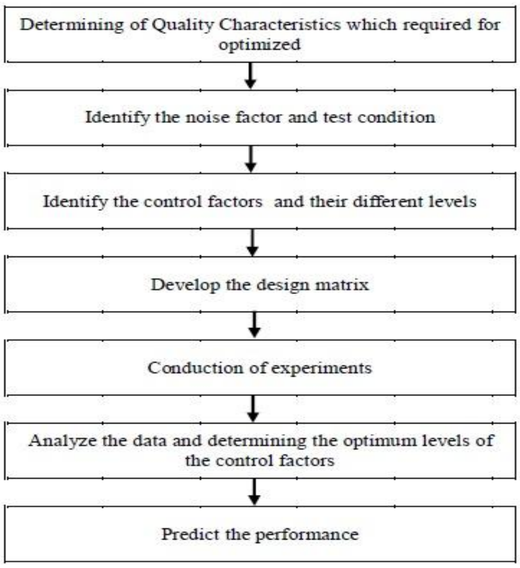


Fig.2: Flow Chart of Taguchi Method [13]

B. Workpiece and Cutting Tool

The workpiece used for this experimentation is OHNS (Oil Hardened Non-shrinkage Steel). The chemical composition of this material is shown in table given below

Table1: Chemical Composition of OHNS

C	0.921%
Mn	1.34%
Cr	0.43%
Ni	0.06%
Mo	0.01%
W	0.42%
V	0.16%
S	0.028%
P	0.025%
Si	0.24%

The hardness of OHNS is 210 BHN. The insert used for this study is manufactured by WIDIA. The insert used was CNMG120404. It is carbide based cutting tool. It is excellent for machining most steels, stainless steels, non ferrous materials and super alloys under suitable conditions. The code CNMG120404 indicates that, it is having a cutting edge length of 12 mm with a thickness of 4 mm and cutting point radius of 0.4 mm. The insert was placed on a right-hand tool holder with a designation of PCLNL2020K1219A.

C. Machine used for experimentation

The machine used for this experimentation is CNC Lathe, which is manufactured by Jyoti. The control panel used for this CNC Lathe is manufactured by Siemens. The specifications of CNC Lathe are given below,

Mode l= DX-150, Input Voltage = 415±10% Volts, Input Power =20 KW, Spindle Power = 05/07 KW, Working Temperature= 10^0 C to 50^0 C, Spindle speed Range= 50 to 3000 RPM, Maximum Rapid Spindle speed= 24000 mm/min.

D. Machining Parameters and Their Levels

The machining parameters used for this study are spindle speed, feed rate and depth of cut. Taguchi's L9 Orthogonal Array is used for experimentation. The levels selected are as follows,

Parameters	Levels		
	1	2	3
Spindle Speed (rpm)	1200	1800	2400
Feed (mm/rev)	0.05	0.1	0.15
Depth of Cut (mm)	0.2	0.4	0.6

E. Experimental Planning

Spindle Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1200	0.05	0.2
1200	0.1	0.4
1200	0.15	0.6
1800	0.05	0.4
1800	0.1	0.6
1800	0.15	0.2
2400	0.05	0.6
2400	0.1	0.2
2400	0.15	0.4

Table 2: L9 Design matrix

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Effect of Machining Parameters on Tool Tip Temperature

In order to see the effect of Machining parameters on Tool Tip Temperature, experiments were conducted using L9 OA (Table 2).

Table 3: Response Table for Signal to Noise Ratios

Level	Spindle Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	-52.82	-53.20	-52.35
2	-53.11	-52.95	-53.16
3	-53.26	-53.03	-53.68
Delta	0.44	0.25	1.34
Rank	2	3	1

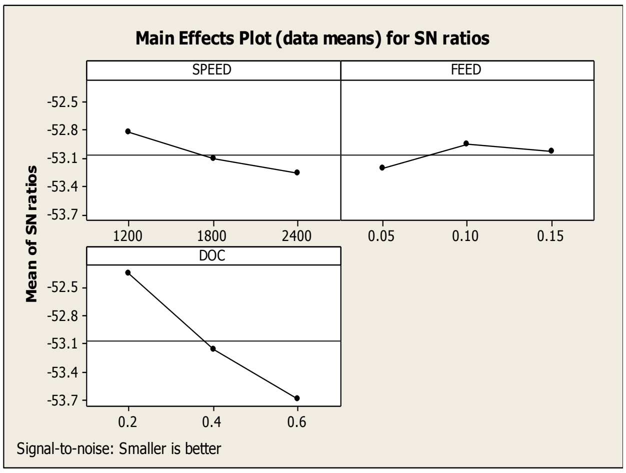


Fig.3: Main Effects Plot for SN ratios

Table 4: Response Table for Means

Level	Spindle Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	438.3	459.0	414.3
2	453.3	445.0	455.3
3	461.3	449.0	483.3
Delta	23.0	14.0	69.0
Rank	2	3	1

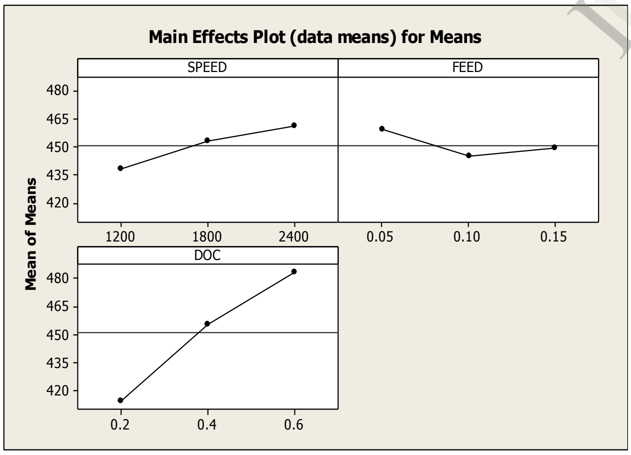


Fig.4: Main Effects Plot for Means

Fig.3 shows the Main Effect plot for S/N ratio. The level for a factor with the highest S/N ratio was the optimum level for response measured. From the plot, it is observed that the minimum tool tip temperature was at the higher S/N values in the response graph. The optimal cutting parameters were 1200 rpm spindle speed (level 1), 0.1 mm/rev feed rate (level 2) and 0.2 mm depth of cut (level 1).From S/N ratio graph, it is observed that for tool tip temperature, the depth of cut has the greatest influence on tool tip temperature followed by spindle speed and feed rate. Figures 3 and 4 show graphically the effect of control factors on tool tip temperature. Process parameter settings with highest S/N ratio always give the optimum quality with minimum variance. The graph show the change of ratio when setting of the control factor was changed from one level to another.

B. Analysis of Variance

Table 5: Response Table for Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contrib-ution
Spindle speed (rpm)	2	818.0	409.0	58.43	0.017	9.77
Feed (mm/rev)	2	312.0	156.0	22.29	0.043	3.72
Depth of Cut (mm)	2	7226.0	3613.0	516.14	0.002	86.33
Error	2	14.0	7.0			0.1672
Total	8	8370.0				

C. Multiple Linear Regression Model

To establish the correlation between the cutting parameters (1) Spindle Speed, (2) Feed Rate, (3), Depth of Cut, with the response factor Tool Tip Temperature the multiple linear regression model was obtained using statistical software "MINITAB-14".The terms that are statistically significant are included in the model. Final Equation obtained is as follows ,

Tool Tip Temperature = 358 + 0.0192 (Spindle Speed) – 100 (Feed) + 173 (Depth of Cut)

By substituting the recorded values of the variables for the above equation (1) the tool tip temperature can be calculated. The positive value of the coefficient suggests that the tool tip temperature increases with their associated variables. Whereas the negative value of the coefficient suggest that the tool tip temperature will decrease with the increase in associated variables. The magnitude of the variable indicates the weightage of each of these factors. It is observed from the Equation (1) that the depth of cut has the more effect on tool tip temperature, which is followed by feed rate and spindle speed for the tested range of variables. The important factor affecting the tool tip temperature is the depth of cut and coefficient associated with it is positive. This suggests that the more depth of cut will remove more material from the workpiece surface in the form of chips, which causes the tool to heat more. The coefficient of spindle speed is positive which indicates that increase in tool tip temperature with increase in spindle speed. The coefficient of feed rate is negative which indicate that tool tip temperature decreases with increase in feed rate.

V. CONFIRMATION TEST

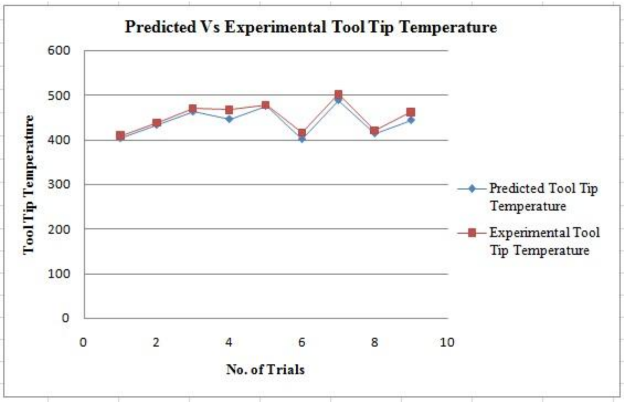
To test the efficiency of the model the confirmation tests were performed by selecting the set of parameters as shown in Table 5.Table 6 shows the comparison of tool tip temperature results from the mathematical model developed in the present work (Eq.(1),with values obtained experimentally. It can be observed from table 6 that the average percentage error in calculated tool tip temperature is 2.12 %.Therefore the multiple regression equation derived above correlate the evaluation of tool tip temperature with the degree of approximation.

Table 5 Parameters used in the confirmation wear test

Test	Spindle speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	1200	0.05	0.2
2	1200	0.1	0.4
3	1200	0.15	0.6
4	1800	0.05	0.4
5	1800	0.1	0.6
6	1800	0.15	0.2
7	2400	0.05	0.6
8	2400	0.1	0.2
9	2400	0.15	0.4

Table 6 Confirmation test results

Test	Predicted tool tip temperature	Experimental tool tip temperature	Error %
1	403.63	408	1.07
2	433.13	437	0.89
3	462.63	470	1.57
4	445.99	467	4.49
5	475.49	478	0.53
6	401.49	415	3.3
7	488.35	502	2.72
8	414.35	420	1.35
9	443.85	462	3.93



The above shows experimental tool tip temperature and predicted tool temperature values are closely related.

III. CONCLUSION

The minimum temperature obtained in this case with the help of optimized cutting parameters (1200 rpm spindle speed, 0.1 mm/rev feed, 0.2 mm depth of cut) is 405.64°C. Basically this investigation is successful in achieving the objective with the acceptable outcome. This experiment evaluates the machining of OHNS with carbide cutting tool. The Taguchi method is very useful in analyzing the optimum condition of parameters and significance of individual parameters to tool tip temperature. In case of tool tip temperature, it has been observed that the depth of cut was the most influencing parameter followed by spindle speed and feed. In order to obtain minimum temperature in case of OHNS within work interval considered in this study, one should use low values of depth of cut and spindle speed .

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