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Influence of Cutting Parameters on the Chip Reduction Coefficient in Hard Turning Process

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ABSTRACT

In the present study, experimental investigation of the effects of the various cutting parameters on the chip reduction coefficient in the hard turning of EN 36 steel is done. The cutting parameters selected for the work was the feed, cutting speed and depth of cut. The objective of the present work is to minimise the chip reduction coefficient which helps to minimise the cutting forces and vibrations. Taguchi L_9 orthogonal array is used to design the experiment and smaller the better is selected to find out the most significant parameter. Analysis of variance was used to do the analysis of the results obtained in the experiment. The percentage contribution of the cutting parameters was calculated using 95% confidence value. From the analysis of the results, it is observed that the depth of cut is the most significant parameters with 49.82 % contribution value and is followed by feed at 20.26 % contribution value.

Keywords : Hard turning, EN36, Chip Reduction Coefficient, ANOVA, Taguchi Method.

I. INTRODUCTION

Turning of the hard to machine materials is the present trend in the manufacturing industry. Hard turning is the term used to describe the turning of the extra hard materials. From long the final precise turning in close tolerances was done with the help of grinding process and with the development of advanced cutting tools such as cubic boron nitride and coated ceramics and carbides, it is now become easy to machine the hard materials on a regular turning machine. The cutting parameters such as feed rate, depth of cut and cutting speed are the primary parameters in the hard turning process. The measurement of the effect of these parameters on response parameters such as chip reduction coefficient is of utmost importance.

Chip reduction coefficient - Chip reduction coefficient can be defined as the ratio of chip thickness to the thickness of the chip which remains undeformed during the machining process. It is also called cutting ratio and is expressed as

Greek letter zeta ζ. Chip reduction coefficient greatly impacts the machining process as larger the value of chip reduction coefficient means more chip thickness, which means more efforts of forces or energy is required to accomplish the machining work. It is always desirable to reduce the chip reduction coefficient with sacrificing material removal rate. The degree of thickening of the chip is expressed by

$$\zeta = \frac{a_2}{a_1} \quad (1)$$

Where, ζ is the chip reduction coefficient, a_1 =fsink_r is the thickness of undeformed chip, a_2 = chip thickness (mm), f = feed rate (mm/rev) and k_r= principal cutting edge angle.

II. LITERATURE REVIEW

Zeqiri et al. [1] studied the effect of the tool geometry and cutting parameters in the chip formation and chip morphology. An experiment was performed on the 42CrMo4 hardened steel with cutting parameters such as cutting speed, feed rate, depth of cut and chip reduction coefficient was the response parameter. A full factorial design of experiment with 38 sets is done and the results are analysed quantitatively. After the detailed analysis of the results, it was found that with the increase in cutting speed and angle of cut the chip reduction coefficient is decreased and there is an increase in the chip reduction coefficient with an increase in the depth of cut.

Khamel et al. [2] investigated the effects of the process parameters like cutting speed, feed rate and depth of cut on tool life, surface roughness and cutting forces in hard turning of AISI 52100 bearing steel. Workpiece material was heat treated to desired hardness of 60 HRC and machining was done with the carbon boron nitride (CBN) tool. Taguchi L27 orthogonal array is used for the design of the experiment, Analysis of variance (ANOVA) and a quadratic model of response surface methodology to find the process parameters that optimise the process characteristics. It was found out that cutting speed has 59.14% effect on the reduction of tool life; surface roughness is affected by feed rate at 64.09%. The depth of cut exhibits maximum influence on cutting force components as compared to feed rate and cutting speed. Optimized parameters for process are speed V_C=168 m/min, feed rate=0.08mm/rev, depth of cut=0.22 mm.

Sahoo et al. [3] investigated the effects of various cutting parameters on the chip reduction coefficient and cutting forces. Taguchi's quality loss function technique was used in the experiment and multi-objective analysis of results was done. Taguchi's smaller the better approach was used to calculate the signal to noise ratios. From the analysis of the results, it is observed that the feed rate is the most influencing parameter followed by the depth of cut to minimise the cutting forces. For chip reduction coefficient, the depth of cut is the most influencing parameter followed by feed rate. Thakur et al. [4] studied the chip characteristics and the tool wear in the turning of Nimonic c263 which is a nickel-based super alloy. The machining of the material is done with the coated and uncoated multilayer carbide inserts. Chip reduction coefficient and tool wear were observed as response parameters. The relative performance comparison between coated and uncoated carbide insert was also given. They found that the chip reduction coefficient decreases with increase in cutting time and cutting speed. The coated carbide insert last longer than an uncoated carbide insert. The flank wear was observed in both inserts and it increases with increase in the cutting time.

Das et al. [5] studied the effects of various cutting parameters such as cutting speed, feed rate and depth of cut on the response parameters such as surface roughness, power consumption, flank wear and chip reduction coefficient in the turning of hardened chromium moly alloy steel. Taguchi's L27 orthogonal array was used in the design of experiment and Analysis of variance was used to analyse the results obtained from the experiment. It is observed that the feed is the most significant parameter to reduce surface roughness. The cutting speed is the most influencing parameter for tool wear and power consumption and depth of cut is the most significant parameter for chip reduction coefficient. Surface roughness was lowest at the feed of 0.1 mm/rev and chip reduction coefficient is least at the depth of cut of 0.3 mm.

III. MATERIALS AND METHODS

The experiment work was conducted on a CNC turning centre in dry cutting condition. The dry or minimum lubrication cutting conditions are one of the main objectives of hard turning. The EN36 nickel-based steel is used in this experiment. “Fig. 1,” shows the experiment setup for the hard turning of workpiece.

Figure 1. Experimental setup

A. Workpiece material

The EN36 steel bar of 40 mm diameter is used in this experiment. The initial length of steel bar was 600 mm which is later cut into two pieces of 300mm length each. The EN36 steel used in this experiment is nickel-chromium-based case hardening steel. The steel bar was supplied in an annealed condition with hardness up to 25 HRC. The hardness of the material was increased with deep carburising and tempering. The EN36 steel retains its chemical and mechanical properties at extreme conditions. The nickel content in material helps to obtain a tough core with a hard surface. The material found its applications in the automobile industry in the production of the engine crankshaft, gudgeon pins, connecting rods and gears.

Table 1: Chemical composition of EN36 steel

C	Mn	Si	Cr	Ni	S	P
0.12-0.18	0.30-0.60	0.10-0.35	0.60-1.10	3.00-3.75	0.05	0.05

The cutting tool used in this experiment was an alumina oxide based ceramic insert with physical vapour deposit (PVD). The insert used in the experiment is an ISO grade TNGA160408 and is provided by Kennametal tools.

B. Design of experiments

In this experiment, the design of the experiment is done with the Taguchi’s method. Taguchi’s method is a statistical tool used to effectively design the experiment by providing a random combination of the input parameter. Taguchi L_9 (3^3) orthogonal array is used in this experiment and input controllable parameters are feed, cutting speed and depth of cut. The experiment has nine degrees of freedom. The chip reduction coefficient is the response parameter selected for optimisation. Taguchi’s method uses the signal to ratio to compute the loss function in collected data. These are used to determine the optimal values of parameters. The smaller the better approach is used to determine the signal to noise value of the response parameters.

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} y_i^2\right) \text{dB} \qquad (2)$$

The main cutting parameters are cutting speed (v), feed (f) and depth of cut (d) and their respective levels are as shown in Table 2.

Table 2 : Process parameters and their levels

Parameter	Unit	Level 1	Level 2	Level 3
Cutting speed (v)	m/min	120	140	180
Feed (f)	mm/rev	0.12	0.16	0.20
Depth of cut (d)	mm	0.15	0.30	0.40

IV. RESULTS AND DISCUSSION

The experimental results for the response variable and calculated signal to noise ratio are given in Table 3. The chip reduction data was calculated using equation

1. The data is analysed using Taguchi's method for the signal to noise (S/N) ratio. The S/N ratios are calculated using smaller the better approach. The main objective of the work is to minimise the chip reduction coefficient. The lesser value of the chip reduction means efficient chip production, lesser vibrations and chattering.

Table 3 : Results for Chip reduction coefficient

Ex N o.	Depth of cut (mm)	Feed (mm/ rev)	Cutting speed (m/min)	CRC	S/N ratio (dB)
1	0.15	0.12	120	1	0
2	0.15	0.16	140	0.625	4.0824
3	0.15	0.20	180	0.45	6.93575
4	0.30	0.12	140	1.083	-0.69257
5	0.30	0.16	180	0.938	0.555943
6	0.30	0.20	120	1.1	-0.82785
7	0.40	0.12	180	1.167	-1.34142
8	0.40	0.16	120	0.813	1.798189
9	0.40	0.20	140	1.2	-1.58362

Table 4 : Response table for mean S/N ratio of chip reduction coefficient

Level	Depth of cut	Feed	Cutting speed
1	3.6727	-0.6780	0.3234
2	-0.3215	2.1455	0.6021
3	-0.3756	1.5081	2.0501
Delta	4.0483	2.8235	1.7266
Rank	1	2	3

Table 4 shows the response table for the mean signal to noise for chip reduction coefficient. The response table shows the effectiveness of the various input parameters on response variables. From Table 4, it is observed that depth of cut is the most effective parameter in minimising chip reduction coefficient and is followed by feed and cutting speed respectively. From Table 3, it is observed that mean S/N ratios for the depth of cut is higher at level 1(d=0.15mm), signal to noise ratios for feed is higher at level 2(f=0.16 m/min) and signal to noise ratios for cutting speed is higher at level 3(v= 180 m/min). Main effect plots

A. The main effect plots for the chip reduction coefficient with various cutting parameters is shown in "fig. 2," The mean effect plots shows the relationship between the means of signal to noise ratio of the response parameter and the process parameters.

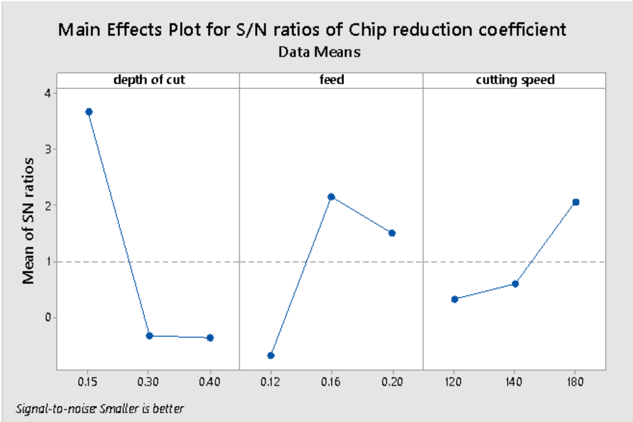

Figure 2. Main effect plots for S/N ratios of Chip reduction coefficient

From figure 2, it is observed that the signal to noise ratio sharply decreases with increase in depth of cut up to some value and remain steady thereafter, with the increase in feed the value of the signal to noise ratio increases sharply up to some level and then decrease steadily with time. In the case of cutting speed, the signal to noise ratio increases steadily with the increase in cutting speed. From mean effect plots, it is clear that the plot between mean S/N ratio and depth of cut has a higher slope which means that chip reduction coefficient increases sharply up to some point. Chip reduction coefficient is mostly affected by the depth of cut and feed and cutting speed has negligible effect.

B. Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistical technique to determine the significance of control parameter over response parameters in the experimental study. The analysis of Chip reduction coefficient is important because it is always desired to decrease the Chip reduction coefficient because it increases disturbance at the cutting zone in chip generation process. The analysis of variance provides the most significant control parameter for Chip reduction coefficient. Table 5 shows the Analysis of variance results for the S/N ratios of surface roughness. The general linear model of the analysis of variance is used in the generation of results. Table 5 shows the value of the degree of freedom, the sum of squares, mean square, F statics and P statics. In the last column percentage contribution of each parameter is given. The depth of cut, feed, cutting speed and error parameter has two degrees of freedom respectively. The value of P statics and F statics represents the significance of the control parameter in the cutting process. The lower value of P statics and higher value of F statics means high significance of concerning parameter.

Table 5 : Analysis of variance for Chip reduction coefficient

Source	DF	Seq SS	Adj SS	Adj MS	F- Value	P- Value	Contribution(%)
Depth of cut (d)	2	32.346	32.346	16.173	2.27	0.306	49.82
Feed (f)	2	13.157	13.157	6.579	0.92	0.520	20.26
Cutting speed (v)	2	5.156	5.156	2.578	0.36	0.735	7.94
Error	2	14.272	14.272	7.136			21.98
Total	8	64.931					100.00

From Table 5, it is observed that depth of cut is the most significant control parameter having percentage contribution of 49.82 % followed by feed having a contribution of 20.26 % and cutting has the least significance in turning process. The percentage error contribution of 21.98 % represents that there are some external factors such as chip design and cutting forces affecting the response parameter.

V. CONCLUSION

In the present study, the analysis of the chip reduction coefficient in the hard turning of the EN36 steel with a ceramic cutting insert is given. The following, conclusions are drawn after the experimental analysis.

1. The Chip reduction coefficient value as low as 0.45 is achieved at the depth of cut d= 0.15mm, feed f= 0.2 mm/rev and cutting speed v= 180 m/min and the highest value of the Chip reduction coefficient is observed at the depth of cut d= 0.40 mm, feed f= 0.2 mm/rev and cutting speed v= 140 m/min. The optimum machining conditions for minimum Chip reduction coefficient are depth of cut d= 0.15mm, feed f= 0.16 mm/rev and cutting speed v= 180 m/min.
2. From Analysis of variance results for chip reduction coefficient, it is evident that depth of cut has the highest contribution in minimising chip reduction coefficient. The percentage

contribution of the depth of cut is 49.82 % and contribution of feed and cutting speed is 20.26 % and 7.94 % respectively.

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