Effective use of Cutting Parameters in Turning Process to Enhance Tool life

Monika Singh, Dheeraj Soni

***Abstract*— Machining is the process of removing the excess material from the work piece or unwanted material from the work piece using a cutting tool. The surface finish and tool life obtain in machining process depends upon the various factors like work material, tool material , tool geometry, machine conditions, coolant and feed rate , speed , depth of cut etc.**

The focus of present study deals with finding optimal controlled process parameters to obtain good surface finish as well as here predicted tool life. It also shows the effect of the process parameters; cutting speed, feed rate and depth of cut on tool life. Experiments design and conducted based on Taguchi method and corresponding surface roughness were noted. The most affecting factor on tool life are cutting speed and feed observed after the experimentation. Here it is also concluded that tool life decreases with increases of cutting speed and feed in machining process for CNMG tool and grey cast iron work material combination.

***Index Terms*— Cutting speed, depth of cut, feed, ANOVA, Taguchi, etc.**

I. INTRODUCTION

Tool life is usually the most important practical consideration in selecting cutting conditions. Tool life prediction equations are an important input to machining process optimization models. These approaches attempt to define a set of cutting parameters that enable to reach the cost or productivity objectives. In general the goal of a machining process is to do maximum possible amount of work in the shortest possible time at the lowest possible cost. These objectives, however, are not always compatible. For example, to maximize the output rate (the amount of work done during a certain time) it might sound intuitive to set the cutting parameters at their highest values. However, this would lead to very short tool life and therefore tool costs would become very high. Moreover, due to frequent replacements a lot of productive time would be lost, thus the output rate would drop. On the other hand, machining at very low cutting speeds, feeds and depths of cut would not do any good either. Even though tool-related costs would decrease, machining time would become very long leading to low output rate. This also implies that to do the same amount of work one would need more man- and machine-hours. Thus the operating costs would increase. In addition to these trades-offs a number of other constraints such the quality of the produced part, rigidity of the machine tool and the available power need to be taken into account when choosing the machining parameters. Considering all these aspects allows determining the optimal set of cutting conditions.

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Wear of cutting tools depends on a number of factors. They include the properties of a particular tool, such as its material, geometry and applied coatings, characteristics of the work piece material being machined, cutting parameters, and efficiency of the cooling process and the specifics of the machine tool.

Modelling and optimization are based on the assumption that tool life is deterministic. This implies that when the input parameters, such as the cutting speed, the feed and the depth of cut, are given, the exact tool life can be found. Unfortunately, real machining processes are dynamic. This means that, rather than being constant, cutting parameters fluctuate around their pre-set values. Moreover, there are many other factors that cannot be completely controlled. Consequently tool wear and tool life also vary.

Besides the variation in the cutting conditions, differences in the shape and the internal structure of the tools, other possible sources of variation are non-uniformity of workpiece properties, such as hardness, micro-structure, composition and surface characteristics, variation in coolant concentration and changes in its condition. To this list one could add the characteristics of the machine tool that promote or limit vibrations, behavior of fixture and other supporting equipment when subjected to high cutting forces, actions of the operators and other factors.

Turning is one of machining process in which a tool, describes a helical tool path by moving linearly when the work piece rotates. The tool axis of movement may be in a straight line, or with some set of curves or angles, but they are essentially linear. Usually the term “turning” is one of the special process for the generation of external surfaces by this cutting action, whereas this is an essential cutting action when applied to internal surface (that is, holes of one kind or another) is called as “boring”. The cutting of faces on the work piece (surface perpendicular to its rotating axis), whether with a turning or boring tool, is called as “facing”, and it may be lumped into either category as a subset.

In turning, the speed and motion of the cutting tool is specified with many parameters as shown in figure 1.1. Out of these the parameters affecting the surface roughness of a metal those are selected for every operation based upon the work-piece and tool material, tool size, etc.

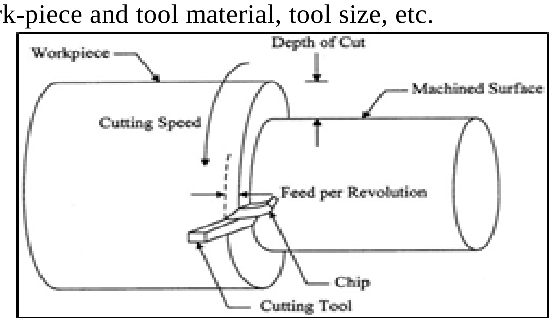

Figure 1. Basic Operation

Cutting Speed (Vc): The term cutting speed of a tool is the speed at which the material is removed by the tool from work piece. In a lathe work it is like peripheral speed of the work piece in m/min.

$$Vc = \frac{\pi DN}{1000}$$ (m/min)……………………………………..……. (1.1)

Where, D and N are diameter (mm) and cutting speed (rpm) of work piece respectively.

Feed (f): The feed of the cutting tool in lathe operation is the linear distance, the tool advances for each revolution of the work piece in mm.

Depth of cut (d): The term depth of cut is the measured perpendicular distance from finished machine surface to the rough surface of the work piece on mm.

A group of researchers have found that cutting parameters (Feed rate, Cutting Speed, Depth of Cut, material properties of tool and tool geometry) directly influence the tool life and surface finish of machined components. For any given machining operation determination of the optimum cutting parameters involves difficulty in between minimizing surface roughness and maximizing material removal rate.

II. LITERATURE REVIEW

Literature study is rich in terms of turning operation owing to its importance in metal cutting. The important cutting process parameters in this research are speed, feed and depth of cut. In addition, it also depends on the several other exogenous factors such as: work piece and tool material combinations and their mechanical properties, quality and type of the machine tool used, lubricant used, and vibrations created between the work piece, machine tool and cutting tool. **Khan et al. (2012) [1]** have outlined experimental results in their study following finish turning of Inconel 718 using low concentration PCBN inserts. **Davin (2012) [2]** discussed the phenomena of tool wear in machining composite materials with various types of cutting tool materials. A discussion of various cutting tool materials was first given and the important properties required for cutting composites were highlighted. **Honghua et al. (2012) [3]** adopted the new material tools, which are polycrystalline diamond (PCD) and polycrystalline cubic boron nitride (PCBN) tools, were used in high-speed milling of Ti-6.5Al-2Zr-1Mo-1V (TA15) alloy. Here, the performance and wear mechanism of the tools were investigated. **Wojciechowski et al. (2012) [4]** studied a comparison of tool life of sintered carbide (with TiAlN coating) and cubic boron nitride (CBN) ball end mills. Experiments were carried out on hardened steel X155CrVMo12-1 plate during milling process with a constant surface inclination angle (α) and variable cutting speeds (v_c) and feeds (f_z). **Saedon et al. (2012) [5]** studied about the development the first and second order tool life models of micro milling hardened tool steel AISI D2 62 HRC. The models were developed in terms of cutting speed, feed per tooth and depth of cut, using response surface methodology. **Gokulachandran et al. (2012) [6]** adopted a model for predicting tool life when end milling 1S2062 steel using P30 uncoated carbide tipped tool under various cutting conditions. A tool life model was developed from regression model obtained by using results of the experiments conducted. **Harish et al. (2013) [7]** in their study experimental work has been carried out for the optimization of input parameters for the improvement of quality of the product of turning operation on CNC machine. Feed rate, spindle speed & depth of cut were taken as the input parameters and the dimensional tolerances as output parameter. In this work of an author L9 array has been used in design of experiment for optimization of input parameters. This study attempted to introduce and verify experimentally as to how the Taguchi parameter design could be used in identifying the significant processing parameters and optimizing the surface roughness in the turning operation. **Rao et al. (2013) [8]** studied about finding optimal control parameters to get the minimum Surface roughness. It considers the analysis of effect of the process parameters, cutting speed, feed rate and depth of cut on cutting forces during turning operation. **Rao et al. (2014) [9]** proposed an alternative approach to determine the optimal process parameters used to predict cutting forces, tool life and surface finish. Experiments have been conducted in three stages by varying different parameters i.e., speed, feed and depth of cut. The tool life has been evaluated by varying the above said cutting conditions for different aluminum work pieces using tungsten carbide cutting tool on a CNC turning machine. **Krolczyk et al. (2015) [10]** determined the coated carbide tool life and the tool point surface topography. The study determined the cutting conditions in the process of turning duplex stainless steel (DSS), and detailed identification of wear mechanisms occurring on the rake face and major flank. The results of wear occurring on both tool points were compared with the width of the flank wear in relation to the period of the steady-state wear of the tool point.

The above literature reviews clearly indicates that the study of cutting speed, feed and depth of cut on cutting force and surface roughness has been very active from the past several decades, but there is a continuous need to extend this study for the different combinations of tool and work material.

III. METHODOLOGY

Every experimenter develops a nominal process that has the desired functionality as per user's demands. Beginning with these nominal processes, aims to optimize the processes/products by suitable methodologies.

The word "optimization" in Taguchi method implies "determination of best levels of process control factors". In turn, the best process control factors are those which maximize the Signal to Noise ratios. The Signal to Noise ratios are log functions of desired output characteristics. Experiments which are conducted to determine the best levels, are based on "Orthogonal Arrays (OA)" are needed to balance with respect to all process control factors and yet are minimum in number. This implies that the resources (type of materials and time) required for the experiments are also minimum.

A. Orthogonal Array

Testing with orthogonal array is similar to a black box testing technique which is the statistical way of software testing. It is needed when the number of inputs to the system is relatively small, but so large to allow for exhaustive testing of every possible input to the system. Arrays are mainly effective in finding errors associated with faulty logic within computer software. Orthogonal arrays can be applied in user interface testing, performance testing and regression testing.

The permutations of factor levels satisfying a single treatment are so chosen that their responses are uncorrelated. Hence each and every treatment gives a unique piece of information. The overall effect of organizing the experiment in such treatments gives same piece of information which is gathered with the minimum number of experiments.

B. Design of experiments

The design of experiments is the design of many tasks that aims to describe or explain about the variation of information under given conditions that are hypothesized to reflect the variation. The term is usually associated with true experiments in which the design allows conditions that directly affect the variation, but it also refer to the design of quasi experiments, in which natural conditions that influence the variation are selected for observation.

In its simplest form, the experiment aims at predicting outcome by introducing a change of the preconditions, which is reflected in a variable known as the predictor. The change in the predictor is generally hypothesized to result in a change in the second variable, hence it is called outcome variable. Experimental design involves the selection of suitable predictors with outcomes and planning the delivery of the experiment under statistically optimal conditions.

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Main concerns in design of experiment include the establishment of validity, reliability, and replicability. These concerns can be partially addressed by choosing the predictor with reducing the risk of measurement error and ensuring that the documentation of the selected method is sufficiently detailed. These related concerns include achieving appropriate levels of statistical power and sensitivity.

C. Analysis of Variance (ANOVA)

The terminology of ANOVA is largely from the statistical design of experiments. In any experiment experimenter adjusts factors and measures responses in an attempt to determine an effect. The factors are assigned to experimental units with a combination of randomization and blocking to ensure the validity of the results. Responses show a variability that is partially the result of the effect and is partially random error. Analysis of variance is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is so difficult to define precisely.

In "ANOVA" result, it has long enjoyed the status of being the most used statistical technique in psychological research. The concept Analysis of variance is probably the most useful technique in the study of statistical inference.

D. Machine and work material

The turning operation was conducted using Hyundai-kia VTL (Vertical Turning Lathe) which is the industrial type of CNC lathe machine with the operating range of spindle speed from 50 rpm to 2500 rpm, and a 10 KW motor drive. Generally, this type of machine used for machining of heavy and heighted parts. The insert type was CNMG120408-TM T9125 and CNMG432 TM T9125. The material used was a EN GJS-500- 7 grey cast iron. The part (370 mm in diameter and 120 mm in height) were machined under wet condition. The work material were trued, centered and cleaned by removing a 0.8 mm depth of cut from the outside surface at the time of machining. Then this setup was used for experimentation as per the designed arrays. Figure 2 shows work piece and figure 3 shows the cutting tool set as follows. The tool and work piece material combination selected as per the cost and time of machining concerned.

Figure 2.Work piece for experimentation

Figure 3.Cutting tool

E. Selection of process parameters

The process parameters that may affect the machining characteristics of parts by CNC turning machine have been selected based on literature review. The identified process parameters are:

- Tool related parameters: tool material, tool geometry, insert coating, grade and insert condition.
- Machining related parameters: cutting speed, feed, and depth of cut.

- The ranges of cutting process parameters for the experiment are decided on the basis of literature survey and the results of pilot experiments conducted using one parameter at a time approach.

TABLE I
PROCESS PARAMETERS

Parameters	Level 1	Level 2	Level 3
Cutting Speed (m/min)	250	350	450
Feed(mm/rev)	0.15	0.25	0.35
Depth of cut (mm)	0.25	0.35	0.45

IV. EXPERIMENTAL PROCEDURE

The experimental setup is shown in Figure. The 9 experiments were conducted based on the experimental array. Wet cutting was performed under suitable a cutting fluid, manufactured by Mobil. It is conventional milky soluble oil, which forms a stable emulsion when mixed with water. This cutting condition was implemented using a developed cutting fluid delivery system. The delivery system parameters were set at 10 ml/h delivery rate. The nozzle was attached to a flexible holder to allow adjusting the direction of cutting fluid delivery.

V. RESULT AND DISCUSSION

The results of experiments are transformed into a signal to noise ratio to measure the deviation of the performance characteristics from the desired values. In this experiment, the desired characteristic for Tool Life is larger the better. The tool used throughout the study was confirmed to ISO designation CNMG120408. A preliminary study on the tool wear behavior of the selected tool was carried out before conducting the experiment to understand the behavior of tool wear. The cutting speed 150-450 m/min, feed rate 0.1-0.45 mm/rev and depth of cut 0.25-0.45 were selected as per the cutting tool and work piece material condition. The time for each run was recorded for total tool life in terms of time. The respective Ra value also recorded for each trial which one important as per quality point of view.

Figure 4.Experimental setup.

TABLE II
RESPONSE OF EACH DESIGN MATRIX
SIGNAL TONOISE RATIO FOR TOOL LIFE

Cutting Speed	Feed	Depth of cut	Ra	O/p Time	Amount of material removed
(m/min)	(mm/rev)	mm	µm	Sec	cm
250	0.15	0.25	0.5	1275	199.22
250	0.25	0.35	0.7	1550	565.1
250	0.35	0.45	1.3	804	527.63
350	0.15	0.35	0.8	1160	355.25
350	0.25	0.45	1.0	840	551.25
350	0.35	0.25	1.2	567	289.41
450	0.15	0.45	0.9	684	346.28
450	0.25	0.25	1.1	708	331.88
450	0.35	0.35	1.5	450	413.44

TABLE III
SIGNAL TO NOISE RATIO FOR TOOL LIFE

Vc	Feed	DOC	Tool Life (min)	SNRA
250	0.15	0.25	21.25	26.55
250	0.25	0.35	25.83	27.97
250	0.35	0.45	13.40	23.05
350	0.15	0.35	19.33	24.30
350	0.25	0.45	14.00	21.82
350	0.35	0.25	9.45	20.58
450	0.15	0.45	11.40	21.64
450	0.25	0.25	11.80	21.85
450	0.35	0.35	7.50	17.50

TABLE IV
ANALYSIS OF VARIANCE FOR TOOL LIFE

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	49.69	49.69	24.85	37.81	0.026
Feed	2	40.34	40.34	20.17	30.70	0.032
DOC	2	4.48	4.48	2.24	3.41	0.227
Residual Error	2	1.314	1.314	0.66	--	--
Total	8	95.84				

The analysis of variance (ANNOVA) results indicate that cutting speed and feed have significant influence on tool life. This study is undertaken by group of researchers which was conducted with different tool and material combination.

VI. CONCLUSION

In this study, CNC turning operation is done under various experimental conditions and the material removal rate, surface roughness, tool life in time were measured. 9 levels of experiments had been done. The most affecting factors on tool life are cutting speed and feed observed after the experimentation. The optimum parameter for this tool and material condition are Cutting speed-250m/min, Feed-

0.15mm/rev and depth of cut-0.35mm. Here it also conclude that tool life decreases with increase of cutting speed and feed in machining process for this tool and material combination.

REFERENCES

[1] S. A. Khan, S. L. Soo, D. K. Aspinwall, C. Sage, P. Harden, M. Fleming, A. White and R. M. Saoubig, "Tool wear/life evaluation when finish turning Inconel 718 using PCBN tooling," Procedia CIRP, vol. 1, pp. 283 - 288`, 2012.
[2] J. Sheikh-Ahmad and J. P. Davim, "Tool wear in machining processes for composites," Woodhead Publishing Limited, pp. 116 - 153, 2012.
[3] S. Honghua, L. Peng, F. Yucan and X. Jiuhua, "Tool life and surface integrity in high-speed milling of titanium alloy TA15 with PCD/PCBN tools," Chinese Journal of Aeronautics, vol. 25, pp. 784 - 790, 2012.
[4] S. Wojciechowski and P. Twardowski, "Tool life and process dynamics in high speed ball end milling of hardened steel," Procedia CIRP, vol. 1, pp. 289 - 294, 2012.
[5] J. B. Saedon, S. L. Soo, D. K. Aspinwall, A. Barnacle and N. H. Saad, "Prediction and optimization of tool life in micromilling AISI D2 (62 HRC) hardened steel," Procedia Engineering, vol. 41, pp. 1674 - 1683, 2012.
[6] G. J. and M. K., "Application of regression and fuzzy logic method for prediction of tool life," Procedia Engineering, vol. 38, pp. 3900 - 3912, 2012.
[7] H. Kumar, M. Abbas, D. A. Mohammad and H. Z. Jafri, "Optimization of cutting parameters in CNC Turning," IJERA, vol. 3, pp. 331 - 334, 2013.
[8] B. T. Rao, D. K. Srinivas, D. P. R. Reddy, A. Raveendra and D. B. R. Kumar, "Experimental study on the effect of cutting parameters on surface finish obtained in CNC turning operation," IJIRSET, vol. 9, pp. 4547 - 4555, 2013.
[9] C. J. Rao, D. Sreeamulu and A. T. Mathew, "Analysis of tool life during turning operation by determining optimal process parameters," Procedia Engineering, vol. 97, pp. 241 - 250, 2014.
[10] G. M. Krolczyk, P. Nieslony and S. Legutko, "Determination of tool life and research wear during duplex stainless steel turning," Archives of civil and mechanical engineering, vol. 15, pp. 347 - 354, 2015