Optimization of Cutting Parameters in Turning Process to Enhance Tool life

Shrinivas D. Chilveri[1], *M.E.Student*, Prof A.R. Suryavanshi[2], *Assistant Professor*, *Mechanical Engineering Department (ZCOER)*

***Abstract*—Modern manufacturers are seeking to remain competitive in the market by relying on their manufacturing engineers and production personnel to effectively set up manufacturing processes for new products. The focus of present experimental study deals with finding optimal controlled process parameters to obtain good surface finish as well as to predict tool life. It considers the process parameters such as cutting speed, feed rate and depth of cut in machining of grey cast iron. Experiments are designed and conducted based on Taguchi method and corresponding surface roughness are noted. Analysis of Variance (ANOVA) verifies the working ranges of the process parameters. Finally it will result to get optimum cutting parameter with required surface finish and improved tool life.**

***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 parts, 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.

"This work was supported in part by **(KIPL)** Kranti Idustries Pvt. Ltd, Pirangut".

Shrinivas Chilveri[1] is with the M.E. student, ZCOER, Pune-411041 (e-mail: shrinivaschilveri@gmail.com).

A. *Metal cutting*

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. 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.

- 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.

$$Vc = \frac{\pi DN}{1000} \text{ (m/min)}$$

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 in mm.

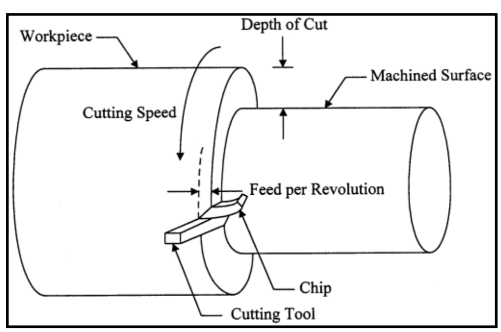

Figure 1. Basic Operation

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 surface finish of machined components. However, out of this cutting force and feed force are former prominently influences power consumption and this work considers only on cutting force as one of the important factor. Surface roughness is also a vital measure as it may influence frictional resistance and fatigue strength of machined components. As far as turned components are concerned, better surface finish is important as it able to reduce the need of further machining. Many researchers have found that surface roughness has bearing on heat transmission at time of machining, ability to hold lubricant, surface friction, wearing etc. 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. C.J. Rao et. al. [1] explained about determination of the optimum cutting conditions, one has to estimate tool life and cutting forces with the reasonable degree of accuracy as many of the constraints those are applying on a process are influenced by these parameters. For a practical machining situation, there are no adequate machining theories available to predict the tool life and cutting forces, one is compelled to rely on empirical equations to predict these process parameters. W.H. Yang et. al. [2] used Taguchi method, a powerful tool to design optimization for quality and to find out the optimal cutting parameters in turning operations. An orthogonal array, the analysis of variance (ANOVA) and the signal to noise (S/N) ratio are used to investigate the cutting process characteristics of S45C steel bars using tungsten carbide cutting tools. Ashvin J. Makadia and J.I. Nanavati [3] adopted design of experiments to study the effect of the important turning process parameters such as tool nose radius, cutting speed, depth of cut and feed rate on the surface roughness of AISI 410 steel. A mathematical model of the surface roughness has been developed for above parameters. And effect of these parameters on the surface roughness has been investigated with the Response Surface Methodology (RSM). Dr. C. J. Rao et.al [4] adopted that depth of cut has a significant influence on cutting force, but also it has an insignificant influence on surface roughness in their study. The interaction of feed and depth of cut and the interaction of all the cutting parameters have influence on cutting force, whereas, none of the interaction effects are having better influence on the surface roughness produced. For this analysis of variance with adjusted approach has been adopted. S.K. Choudhury and I.V.K. Appa Rao [5] explained a new approach for improving the cutting tool life with the help of optimal values of velocity and feed throughout the process. A tool life equation has been established from experimental data as well as the adhesion wear model. Here also optimization techniques are implemented to maximize the tool life subject to maintain a constant metal removal rate. Jihong Yan and Lin Li [7] adopted multi-objective optimization method based on RSM, which is applied to optimize the parameters in milling process in order to evaluate trade-offs between sustainability, production rate and cutting process quality. Here three objectives, such as surface roughness and material removal rate are simultaneously optimized. Behnam Davoodi and Behzad Eskandari [16] explained that the effects of cutting or process parameters on tool life of PVD TiAlN-coated carbide tools as well as volume of work piece material removed during the machining of the N-155 iron–nickel-base super alloy are evaluated. The relationships between machining parameters and output variables were modeled with the help of response surface methodology. ANOVA (Analysis of variance) was performed to check the accuracy of the mathematical model and its respective variables.

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

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 for efficient fluid delivery. The nozzle was fixed on the tool holder to ensure continuous cutting fluid delivery at the cutting point throughout the whole cutting process. 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.

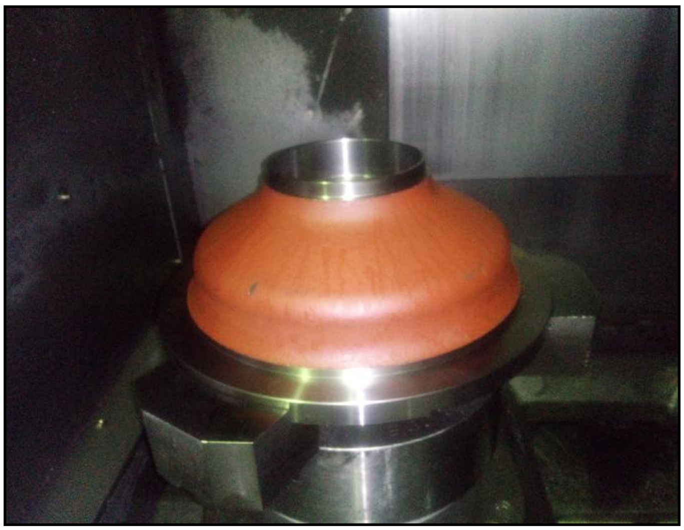

Figure 4.Experimental setup

TABLE II
RESPONSES OF EACH DESIGN MATRIX

Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut mm	Ra µm	O/p Time Sec	Amount of material removed 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

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.

$$\frac{S}{N} = -10\ log\left[\frac{1}{n}\sum(y_i)^2\right]$$

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

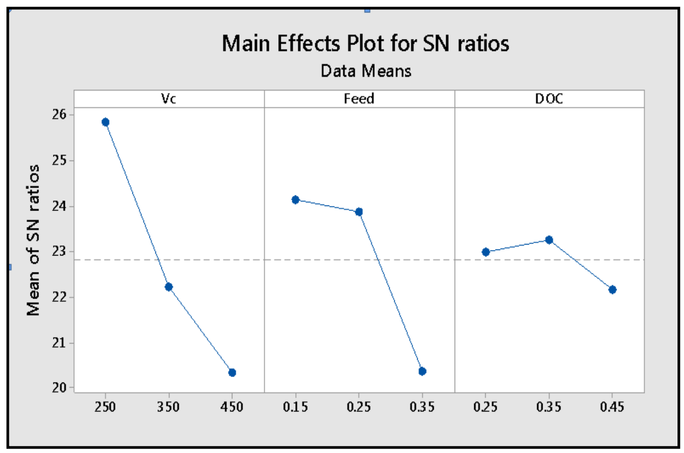

Figure5. Main Effects of Plot for Tool Life

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 [4].

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] C.J.Rao, D.Sreeamulu and Arun Tom Mathew, "Analysis of Tool Life during Turning Operation by Determining Optimal Process Parameters", Procedia Engineering, 97 (2014) 241 – 250

[2] W.H. Yang and Y.S. Tarng, "Design optimization of cutting parameters for turning operations based on the Taguchi method", Journal of Materials Processing Technology, 84 (1998) 122–129

[3] Ashvin J. Makadia and J.I. Nanavati, "Optimization of machining parameters for turning operations based on response surface methodology", Measurement, 46 (2013) 1521–1529

[4] Dr. C. J. Rao , Dr. D. Nageswara Rao and P. Srihari, "Influence of cutting parameters on cutting force and surface finish in turning operation", Procedia Engineering, 64 (2013) 1405 – 1415

[5] S.K. Choudhury and I.V.K. Appa Rao, "Optimization of cutting parameters for maximizing tool life", International Journal of Machine Tools & Manufacture, 39 (1999) 343–353

[6] K. Kadirgama, K.A. Abou-El-Hossein, M.M. Noor, K.V. Sharma and B. Mohammad, "Tool life and wear mechanism when machining Hastelloy C-22HS", Wear, 270 (2011) 258–268

[7] Jihong Yan and Lin Li, "Multi-objective optimization of milling parameters e the trade-offs between energy, production rate and cutting quality", Journal of Cleaner Production (2013) 1-10

[8] Francois Ducobu, Pedro-Jose Arrazola, Edouard Riviere-Lorphevre and Enrico Filippi, "Finite element prediction of the tool wear influence in Ti6Al4V machining", Procedia CIRP, 31 (2015) 124 – 129

[9] Ahmed A. D. Sarhan, " Adaptive neuro-fuzzy approach to predict tool wear accurately in turning operations for maximum cutting tool utilization", IFAC-Papers On-line, 48-1 (2015) 093–098

[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 15 (2015) 347–354

[11] R.S. Kadu, G.K. Awari, C.N. Sakhale and J.P. Modak, "Formulation of Mathematical Model for the Investigation of tool wears in Boring Machining Operation on Cast Iron using Carbide and CBN tools", Procedia Materials Science, 6 (2014) 1710 – 1724

[12] H.V. Ravindra, Y. G. Srinivasa and R. Krishnamurthy, "Modeling of tool wear based on cutting forces in turning", Wear, 169 (1993) 25-32

[13] Ihsan Korkut , Mustafa Kasap , Ibrahim Ciftci and Ulvi Seker, "Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel", Materials and Design 25 (2004) 303–305

[14] Aldo Attanasio, Elisabetta Ceretti and Claudio Giardini, "Analytical Models for Tool Wear Prediction during AISI 1045 Turning Operations", Procedia CIRP, 8 (2013) 218 – 223

[15] Rajesh Kumar Bhushan, "Optimization of cutting parameters for minimizing power consumption and maximizing tool life during machining of Al alloy SiC particle composites", Journal of Cleaner Production, 39 (2013) 242-254

[16] Behnam Davoodi and Behzad Eskandari ,"Tool wear mechanisms and multi-response optimization of tool life and volume of material removed in turning of N-155 iron–nickel-base superalloy using RSM", Measurement 68 (2015) 286–294

[17] S.K. Choudhury and K.K. Kishore,"Tool wear measurement in turning using force ratio", International Journal of Machine Tools & Manufacture, 40 (2000) 899–909

Shrinivas Durgadas Chilveri 1 received the B.E. degree in Mechanical Engineering from Pune University, Pune, India in 2013.He is currently Pursuing his Masters Degree in Computer Aided Design Manufacturing and Engineering CADME from ZCOER, Savitribai Phule Pune University, Pune, India. He holds an experience in Production as Junior Engineer from Kranti Industries Limited Pune, India. His research interests are development of process and analysis.