THEORETICAL STUDY OF TOOLING SYSTEMS AND PARAMETRIC OPTIMIZATION OF TURNING OPERATION ON STAINLESS STEEL USING A CARBIDE TOOL

Mr. Vijay Kumar[1], Mr. Bijender Kumar[2]

[1]*Master of Technology Scholar, Dept. of Mechanical Engineering, Mata Raj Kaur Institute of Engineering & Technology, Rewari, Haryana, India*
[2]*Assitant Professor, Dept. of Mechanical Engineering, Mata Raj Kaur Institute of Engineering & Technology, Rewari, Haryana, India*

***

Abstract - *Micro turning operation is used to refer to operation processes occurring at dimensions of 1 to 999 micro meters. Stainless steel is a widely used material in day to day applications. In this case, a carbide tool has been used to machine stainless steel. The machining parameters are cutting speed, feed and depth of cut. The main aim is to understand the optimum settings of these parameters to reduce the machining forces, namely the feed force, the thrust force and the cutting force. To better understand these effects, experiments were carried out on a lathe and the machining forces measured with a dynamometer. The mode of machining was chosen as wet machining. The Taguchi method was used to analyze the obtained results. The statistical software MINITAB was then used to confirm the results obtained from statistical analysis.*

Key Words: **Cutting speed, Feed, Depth of cut, Thrust force, Feed force, Cutting force, Dynamometer, Minitab.**

1. INTRODUCTION

Cutting and edge tools, such as the knife, scythe or sickle, are wedge-shaped implements that produce a shearing force along a narrow face. Ideally, the edge of the tool needs to be harder than the material is being cut or else the blade will become dulled with repeated use. But even resilient tools will require periodic sharpening, which is the process of removing deformation wear from the edge. Other examples of cutting tools include gouges and drill bits. Moving tools move large and tiny items. Many are levers which give the user a mechanical advantage. Examples of force-concentrating tools include the hammer which moves a nail or the maul which moves a stake. These operate by applying physical compression to a surface. In the case of the screwdriver, the force is rotational and called torque. By contrast, an anvil concentrates force on an object being hammered by preventing it from moving away when struck. Writing implements deliver a fluid to a surface via compression to activate the ink cartridge. Grabbing and twisting nuts and bolts with pliers, a glove, a wrench, etc. likewise move items by some kind of force. Micro turning is similar to conventional turning operation but the work piece and the part produced are much smaller in size. It becomes increasingly difficult to use conventional methods of manual machining to perform the operation as the size of the work piece decreases and the features desired become more detailed. So computerized numerical control machines are used.

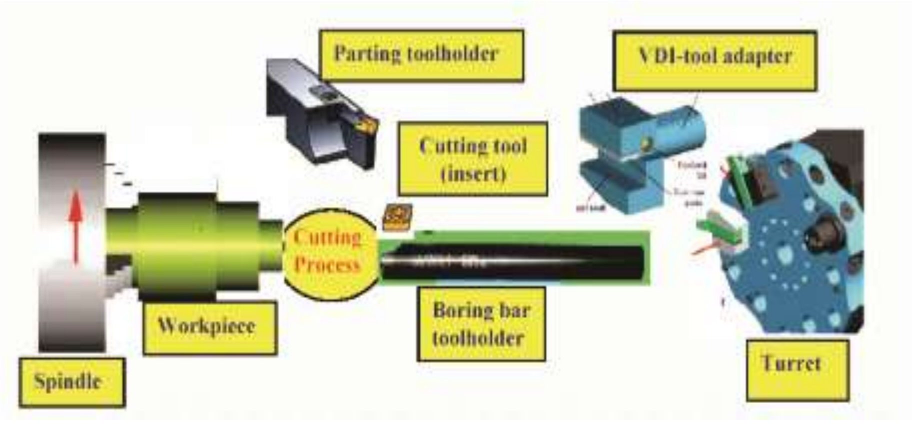


Fig -1: Machine tool components taken in consideration in the project

A few advantages of micro tooling machines like micro turning machines are as follows:

Micro machines aid in the conservation of energy. They help in saving a large amount of energy. In traditional machining, during the production of small parts, a lot of unnecessary energy consumption occurs. For example, a small part may be capable of being produced by the consumption of just 100 W of power. But if a conventional machine is used, it will consume the amount of power it has been designed to consume, say 10kW. So a micro machine consuming 100 W of power is 100 times more efficient than the conventional machine. The world today desires efficiency in the consumption of power with ever increasing demands for energy.

Conventional machining with large machines requires special peripheral equipment to aid in temperature control or vibration isolation. An important factor to ensure precision machining is to keep the temperature of the machine constant throughout the operation. In case of large conventional machines, the temperatures of large spaces, sometimes huge rooms, need to be controlled. Along with the associated complexity, there is unnecessary power consumption to ensure temperature control. But in case of micro machines, the temperature of a small chamber needs to be controlled. Another condition to ensure precision machining is vibration isolation. In case of large conventional machines, in order to isolate internal or external vibrations, the use of vibration free machine bed or even special building is necessitated. However, a micro machine does not need such systems. The natural frequency of micro machines is normally higher than that of vibrations caused by surroundings.

1.1 Literature Review

Eugen Axinite has studied the surface roughness on micro turning of titanium alloys (Ti6Al4V). Conventional turning on these titanium alloys is difficult. Firstly, the tool life is short and then long chips are formed which cause the problem of removal from the machine. So, micro turning of these alloys has gained in importance. When a tool with a nose radius is used, ridges having geometries corresponding to the geometry of the tool nose get left behind on the finished surface. Also, very high normal stresses get developed in the metal at the trailing edge. This metal flows to the side relieving the stress and in the process, creating a furrow increasing the roughness. Particularly, soft ductile materials show this problem. It is observed that in case of micro turning the surface roughness first decreases with feed, reaches a minimum and then increases if the feed is further increased. The final model for prediction of surface roughness consists of roughness of cutting edge, roughness associated with plastic side flow and kinematics‟ surface roughness.

H.S.Yoon has proposed an orthogonal cutting force model based on slip-line field model for micro machining. Two material flow processes are being considered- chip formation process and ploughing. The paper takes into account the effects of parameters like effective rake angle, depth of deformation and minimum chip thickness. The edge radius effect is an important effect in machining processes. The tool can be scaled down to a large extent but the sharpness of the tool cannot be scaled down so drastically and proportionately. So, in micro machining ploughing force is an important factor instead of shearing force which is the dominant factor in conventional machining. Another important effect is the minimum chip thickness effect. When the undeformed chip thickness is below the minimum chip thickness, chip formation doesn’t occur and there is only ploughing. However, when the undeformed chip thickness exceeds the minimum value, chip formation occurs. Some experimental analysis has shown that chip formation occurs only when the undeformed chip thickness is more than 30% of the tool edge radius. This paper is based on the assumption that the tool has a perfectly rounded tool edge. The cutting performed is assumed to be orthogonal. The material deforms plastically below the minimum chip thickness height. Another assumption is that the work material is not work-hardening. So, the shear stresses on all shear planes have the same values. The chip is also assumed to be a free body, such that the normal force on the shear plane is zero. The paper has also concentrated on the effect of the dead metal zones on micro machining. These zones act as stable built up edges on the tool, as stagnation zones where no material flow occurs.

Ajjarapu has made a study of the ductile regime machining of silicon nitride. Depths of cut ranging from 250nm to 10μm are chosen for machinability tests. The Drucker-Prager yield criterion is implemented in the software Advantage to study the mechanical behavior of silicon nitride. Depths of cut ranging from 1 μm to 40 μm and rake angles ranging from 0° to -60° are used for numerical simulations. It was observed that higher negative rake angles result in development of higher pressures in the work piece. Similarly experiments have shown that the regime for machining is ductile when the values of depth of cut chosen are less than 1 micron.

N. Fang has attempted a modeling of built up edge formation in machining. The size of the built up edge can be quantitatively predicted and the effect of built up edge on chip flow and cutting forces can be studied under different machining conditions. The built up edge in machining is an irregular and unstable structure formed on the tool rake surface during machining of ductile materials ad alloys like steels and aluminium alloys. It comprises of several successive layers hardened under extreme strain conditions at the chip-tool interface. This model is very important since it predicts built up edge formation in machining. It also predicts the chip uncurling effect that plays an important role in machining. It establishes the relationship between the size and boundary of the built up edge and machining parameters like chip thickness, chip tool contact length, chip up-curl radius and cutting and thrust forces.

Kim has suggested an orthogonal cutting model called the round edge cutting model. This model has concentrated on two factors, firstly the elastic recovery of the work piece causing sliding along the clearance face and secondly on ploughing. The results of this model have been compared with those of Merchant's model. One of the assumptions is that cutting is a two-dimensional plastic process. The normal stress is assumed to be constant while the shear stress changes in the region where the tool is rounded. The work piece is elastically recovered in the clearance face. It has been observed that for depths of cut less than 1 micron, the round edge cutting model of Kim better approximates the cutting forces compared to the sharp edge cutting model of Merchant. At such low depths of cut, the friction along the flank face and the effective negative rake angle are factors that need to be considered.

Jiwang Yan has attempted to discuss ductile regime turning at large tool feeds. A very important problem in using ductile regime turning is tool wear. The existing method of using a round nosed diamond tool introduces limitations on feed. In this paper, the authors have proposed the use of a straight nosed diamond tool. A small tool feed results in a long cutting distance. If other conditions are kept constant, tool wear volume increases with cutting distance. So, a smaller tool feed leads to a greater tool wear. A small tool feed also results in increased machining time and low machining efficiency. If a straight edged diamond tool is used, undeformed chip thickness becomes uniform along the main cutting edge. So, a uniform cutting mode may be expected. In the diamond turning process, brittle machining involves tensile cleavage fracture while ductile machining involves large-strain plastic deformation. This model adopts small cutting edge angles and thus allows thinning of chip thickness in the range of nanometres. This model enables plain strain conditions too. Ductile regime turning could be done at large tool feeds up to some tens of micrometers.

T.P.Leung has attempted to study the ductile regime diamond turning of silicon substrates. Machining silicon in the brittle regime is not suitable because of its low fracture toughness. The effect of variation in parameters such as depth of cut, feed rate and tool rake angles on ductile regime turning of silicon using a diamond tool needs to be investigated. Three distinct regimes could be observed in the machining process, the elastic regime, the ductile regime and the brittle regime. In the ductile regime, the surface is smooth and it was observed that there were no cracks or pits. The brittle regime has intensive surface cracks. The orientation of the crystal is another factor that affects the critical depth of cut. The size of the cracks increases with increase in the depth of cut. To obtain an optical surface on silicon substrate in diamond turning, the chip thickness must not exceed a critical value.

Blackley has suggested an entirely different model for ductile regime diamond turning of brittle materials. Two parameters, the critical depth of cut and the subsurface layer damage are used to characterise the material removal process. A process limit called the maximum feed rate has been introduced to understand the process better. The effect of the rake angle, tool nose radius and machining environment on the machinability has been studied. The material used for experimental study is germanium and the lubricant used for machining is distilled water. Better machining is observed at highly negative rake angles. However as the rake angles are made more and more negative, the surface finish decreases in quality. It was observed that ductile regime machining for germanium is better in the dry state than in the wet state using distilled water as the lubricant. With an increase in the tool nose radius, the machinability of the material is found to improve. Though an exact explanation of the observed phenomena has not been attempted, it can be speculated that the magnitude and direction of the cutting forces play an important role in the displayed characteristics.

1.2 Minimum Chip Thickness

In micro turning, there is a certain minimum chip thickness which greatly affects variables like cutting force, tool wear, surface integrity and this in turn affects the machining process performance. The concept of minimum chip thickness arises due to the edge radius effect. In micro turning, the tool can be scaled down to a large extent but the sharpness of the tool cannot be scaled down proportionately. So, if the uncut chip thickness is less than the minimum chip thickness, no chip is generated.

1.3 Size Effect

The size effect can have two causes:

1. Statistical, due to material strength randomness, and
2. energetic (and non-statistical), due to energy release when a large crack or a large fracture process zone (FPZ) containing damaged material develops before the maximum load is reached.

For a small depth of cut, the "size effect" phenomenon appears. It consists of a non-linear increase in the specific cutting energy when the depth of cut decreases. The specific cutting energy is the ratio between the total cutting force acting on the tool in the cutting direction and the chip section. The scaling effect would be caused by ploughing of machined material due to negative rake angle, strain rate dependency, dislocation density, pressure on the flank face due to elastic spring back and strain hardening of machined material at micrometrical scale.

1.4 Experimental Design

Guidelines for designing experiment:

- Recognition of and statement of the problem: It is highly essential to fully develop all ideas about the problem at hand and also about the specific objectives of the experiment. Input from all concerned parties- engineering, marketing, customers, quality, management and the operators are to be solicited. This helps in better process understanding and eventually solving the problem. Choice of factors and levels:
- Choices of factors to be varied in the experiment must be made, the ranges over which the factors are varied and the specific levels at which runs are made. Process knowledge is a combination of practical knowledge and theoretical understanding and it is necessary for proper choice. The number of factor levels should be kept low for factor screening. All factors that may be of importance must be examined. Much stress should not be laid on post experience.
- Selection of the response variable: While selecting the response variable, it must be ascertained that the variable actually provides useful information about the process under study. Very often, the mean or standard deviation or both are chosen as response variables.
- Choice of experimental design: Choice of design requires consideration of sample size, selection of a suitable run order for experimental trials and whether or not blocking and other randomization restrictions are involved.
- Performing the experiment: While running the experiment, it is necessary to carefully monitor the process to ensure that everything is being done according to the plan. Errors in experimental procedure at this stage generally destroy experimental validity.

Data analysis: Statistical methods should be used to analyse the data such that results and conclusions are objective and not judgemental. Use of simple graphical methods as well as software is done.

Tool, Dynamometer and W/P Assembly

Work Piece in Chuck

2. TAGUCHI METHOD

This quality design technique was first proposed by Taguchi in the 1960s. It greatly aids in improving industrial product quality. In the preliminary study, feed force was set as the objective function of the micro turning experiment. Three factors, cutting speed, feed and depth of cut are taken as the machining parameters. Taguchi's techniques have been used widely in engineering design (Ross 1996 & Phadke 1989). The Taguchi method contains system design, parameter design, and tolerance design procedures to achieve a robust process and result for the best product quality (Taguchi 1987 & 1993). The main trust of Taguchi's techniques is the use of parameter design (Ealey Lance A.1994), which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. To determine the best design, it requires the use of a strategically designed experiment, which exposes the process to various levels of design parameters. Experimental design methods were developed in the early years of 20th century and have been extensively studied by statisticians since then, but they were not easy to use by practitioners (Phadke 1989). Taguchi's approach to design of experiments is easy to be adopted and applied for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community. Taguchi specified three situations:

Larger the better (for example, agricultural yield);

Smaller the better (for example, carbon dioxide emissions); and

On-target, minimum-variation (for example, a mating part in an assembly

Taguchi realized that the best opportunity to eliminate variation is during the design of a product and its manufacturing process. Consequently, he developed a strategy for quality engineering that can be used in both contexts. The process has three stages:

I. System design

II. Parameter design

III. Tolerance design

2.1 Steps in Taguchi Methodology:

Step-1: Identify the main function, side effects, and failure mode

Step-2: Identify the noise factors, testing conditions, and quality characteristics

Step-3: Identify the objective function to be optimized

Step-4: Identify the control factors and their levels

Step-5: Select the orthogonal array matrix experiment

Step-6: Conduct the matrix experiment

Step-7: Analyze the data, predict the optimum levels and performance

Step-8: Perform the verification experiment and plan the future action.

Table 1: Observation Table

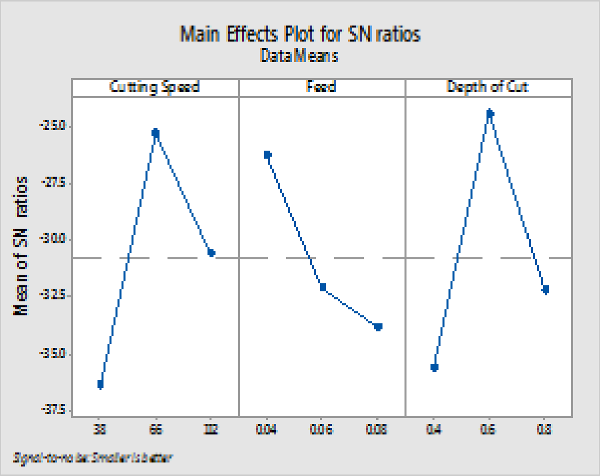
Sr. No.	Cutting Speed	Feed	Depth of Cut
1	38	0.04	0.4
2	66	0.06	0.6
3	112	0.08	0.8

Table 2: L9 Orthogonal Array

Run No.	Cutting Speed(m/min)	Feed (mm/rev)	Depth of Cut(mm)	Feed Force(N)	Thrust Force(N)	Cutting Force(N)
1	38	0.04	0.4	64	64	44
2	38	0.06	0.6	44	18	62

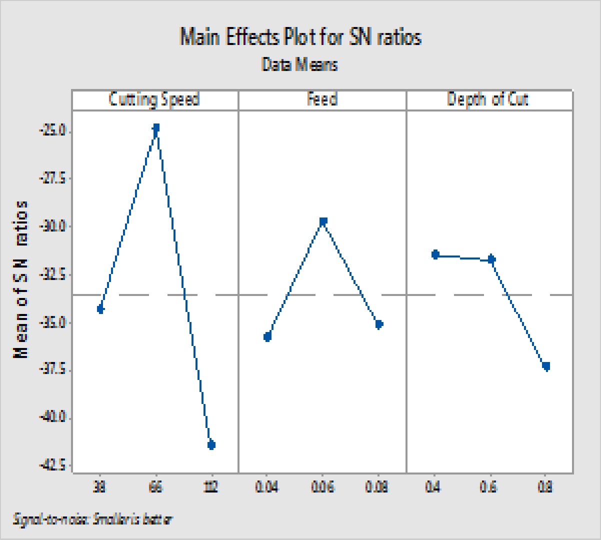
3	38	0.08	0.8	105	121	110
4	66	0.04	0.6	5	23	8
5	66	0.06	0.8	23	21	13
6	66	0.08	0.4	54	11	82
7	112	0.04	0.8	28	159	167
8	112	0.06	0.4	62	75	95
9	112	0.08	0.6	21	139	64

Signal to Noise Ratio for Feed Force Plot and Table:



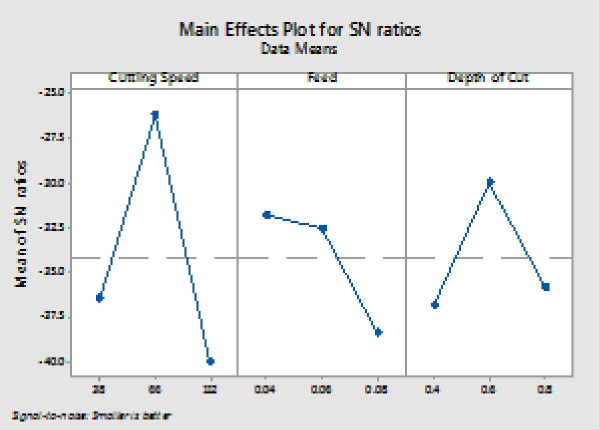
Level	Cutting Speed	Feed	Depth of Cut
1	-36.38	-26.26	-35.58
2	-25.29	-32.12	-24.43
3	-30.55	-33.84	-32.20
Delta	11.09	7.58	11.15
Rank	2	3	1

Signal to Noise Ratio for Thrust Force Plot and Table:



Level	Cutting Speed	Feed	Depth of Cut
1	-34.29	-35.80	-31.48
2	-24.84	-29.68	-31.73
3	-41.46	-35.11	-37.38
Delta	16.63	6.11	5.89
Rank	1	2	3

Signal to Noise Ratio for Cutting Force Plot and Table:



Level	Cutting Speed	Feed	Depth of Cut
1	-36.51	-31.80	-36.90
2	-26.21	-32.56	-30.01
3	-40.04	-38.41	-35.85
Delta	13.84	6.61	6.89
Rank	1	3	2

3. CONCLUSIONS

While studying the effect of the cutting parameters on the feed force, it was observed that both the cutting speed and the depth of cut play equally important roles in the effect on the feed force. The role of the feed given is not crucial to the same extent.

While studying the effect of the cutting parameters on the thrust force, it was observed that the cutting speed exerts a huge influence on the magnitude of the thrust force while the effect of feed and depth of cut on thrust force is comparatively less and equal to each other approximately.

While studying the effect of the cutting parameters on the cutting force, it was observed that the effect of the cutting speed far outweighs the effect of the feed and the depth of cut, which are again roughly equal.

The above mentioned conclusions suggest that a good combination of the input parameters for decreasing feed force, thrust force and cutting force.

3.1 Scope for Further Study

It was planned originally that the effect of the cutting variables (feed, speed and depth of cut) on machining forces in machining through coated carbide tools too would be studied. This could not be accomplished due to the lathe machine not being in operating condition. This can be done in the future and a comparative analysis may be made between coated and uncoated tools to find out the effect of coating on the machining forces.

REFERENCES

[1] Axinte Eugen, ABOUT THE SURFACE ROUGHNESS ON MICROTURNING OF TITANIUM ALLOYS, Universitatea Technical "Gh. Asachi", Iaşi Tomul LIII (LVII), Supliment, 2007 Secţia CONSTRUCŢII DE MAŞINI

[2] H.S. Yoon, K.F. Ehmann, A Slip-line field model for orthogonal micro-machining processes, Department of Mechanical Engineering, Northwestern University, IL, U.S.A.

[3] Satya K. Ajjarapu, Ronnie R. Fesperman, John A. Patten and Harish P. Cherukuri, Ductile Regime Machining of Silicon Nitride: Experimental and Numerical Analyses,Center for Precision Metrology, Department of Mechanical Engineering and Engineering Science The University of North Carolina at Charlotte Charlotte, NC 28223-0001, USA

[4] N. Fang, P. Dewhurst, Slip-line modeling of built-up edge formation in machining, International Journal of Mechanical Sciences 47 (2005) 1079–1098

[5] Jeong-Du Kim, Dong Sik Kim, Theoretical analysis of micro-cutting characteristics in ultra-precision machining, Journal of Materials Processing Technology 49 (1995) 387-398

[6] Jiwang Yana,Katsuo Syoji, Tsunemoto Kuriyagawa, Hirofumi Suzuki, Ductile regime turning at large tool feed, Journal of Materials Processing Technology 121 (2002) 363–372

[7] T.P. Leung, W.B. Lee, X.M. Lu, Diamond turning of silicon substrates in ductile-––regime, Journal of Materials Processing Technology 73 (1998) 42–48

[8] W. S. Blackley and R. O. Scattergood, Ductile-regime machining model for diamond turning of brittle materials, PRECISION ENGINEERING-103

[9] Minimum Chip Thickness in Micromachining", Journal of Manufacturing Science and Engineering, MAY 2006, Vol. 128, pp. 474-481

[10] Taguchi, G.: "Quality Engineering in Japan", Bulletin of the Japan Society of Precision Engineering, Vol 19 No (4), pp. 237-242, (1985).

[11] Taguchi, G.: "Introduction to Quality Engineering - Designing Quality into Products and Processes", Asian Productivity Organization, Tokyo, (1986).

BIOGRAPHY

Vijay Kumar graduated from Rao Pahlad Singh College Of Engineering & Technology, Balana (Mohindergarh) In 2016, Degree in Mechanical Engineering from Maharishi Dayanand University Rohtak, Haryana, INDIA.