International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 13 (2018) pp. 11069-11076

Chatter Stability and Tool Wear Prediction during Orthogonal Turning by Considering Sharp Tool

[1]Anuj Kumar, [2]Munish Kumar, [3]Dr. Ranbir Singh

[1]M.tech BRNIT, [2]M.tech DCRUST, [3]Assistant Professor

[1,2,3] Mechnical Engineering Department . BML Munjal University, India.

Abstract

Chatter vibration has been researched for more than a century and it is still a major problem in achieving automation for most of the machining processes including turning, milling and drilling.The paper focuse on the stability of chatter vibrations and predict the tool wear by considering a single degree of freedom model for orthogonal turning process by considering a sharp tool. The stability lobe diag of orthogonal turning operation are constructed using programming. The effects of self excited chatter vibration on tool wear in order to predict the tool life with the help of tool wear equation. This indicates that the chatter cause tool wear drastically.

Keywords: Tool Wear, Single degree freedom, Stability Lobe diagram

INTRODUCTION

Tool wear is the most common cause of damage to the tool, which also reduces the life of the tool. Tool wear depends on friction and vibration produced during operation of highly cut. Its life is one of the critical factors affecting the cost and productivity.

Self excited autonomous vibrations are very critical machining operations and also a condition that accelerates tool wear. Chatter can be present in all machining operations. Chatter can generate high noise does not cause bad surface finish, tool wear, tool breakage and damage to the machine tool system. Metal removal rate should be reduced to avoid the chatter, which reduces productivity. Chatter has adverse effects on product quality, assembly of the machine tool and production rates, which makes vibration analysis an essential activity. The turning is a machining process in which chatter vibrations frequently occur and affect the quality of life and the machining tool. Therefore, this paper focuses on speech and its effects on tool wear / life in a turning operation vibration.

TURNING INTRODUCTION

The turning operation is the most common and very basic in manufacturing machining. As the object of the present is in the turning operation, it is essential to understand the basic mechanisms of the turning operation.

In the process of rotation, a workpiece rotating about its longitudinal axis in a machine tool of turn. The workpiece is supported by a chuck at one end and against one point to another. A cutting tool rigidly mounted on a post of the tool in the tower is moved along the axis of the workpiece to remove material and produce the required shape. The geometry of a rotation process is shown in Fig. If the cutting tool is disposed perpendicular to the axis of the workpiece, it is called orthogonal rotation.

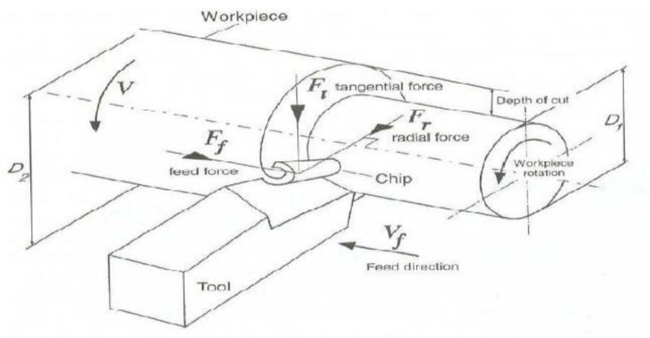


Figure 2.1 Geometry of oblique turning process

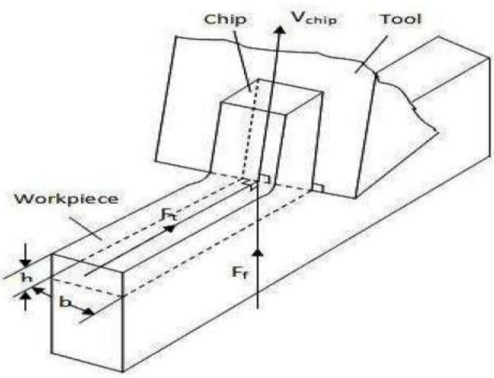


Figure 2.2 Geometry of orthogonal turning process

Vibration during Turning

In a turning process, three different types of mechanical vibrations are present due to the lack of dynamic stiffness of the machine tool system comprising the tool of the tool, tool holder, the workpiece and the machine itself. These are free, forced and self-excited vibrations chatter is perceived as an undesirable excessive vibration between the tool and the workpiece, resulting in a poor surface finish and tool wear accelerated. These are free, forced vibration and self-excited. self excited vibrations chatter still not fully understood, because of its complex nature. They are the most harmful for all machining processes, including turning. Self excited vibrations are generally classified into primary and secondary chatter. Primary chatter is caused by friction between the tool and the workpiece, thermo mechanical effects or by coupling mode. Secondary chatter is caused by the regeneration of the undulated surface of the workpiece

Stability lob diagram

SLD can be used to predict the stability of chatter in a turning process. The depth limit blim(limit depth of cut) cut is plotted against the rotational speed (N) in SLD as shown in a typical similar graph in Fig. 3. vibrations between the tool and the workpiece appear as different lobes (n = 1, 2,3, ...) and the entire cutting depth and spindle speed falls below these lobes results in stable operation and above them (without grazing) lobes in (chat) operation unstable

SCOPE OF RESEARCH

This research focuses on chatter and tool wear prediction and programming and also focuses on relationship between chatter vibration and tool wear as a graph plot but This research restricts to analysis of turning operation only.

OBJECTIVE OF RESEARCH

To carry out a literature survey to understand the recent development in this field and to justify the objective and define the scope of this project. And to make a Programme for chatter stability and tool wear predictions and by the use of programme Minimize/ suppress the chattering and tool wear and increase tool life after that Stabilize the model at varying spindle speed

MATHEMATICAL MODELLING AND DISCUSSION

There are 5 Assumptions as below

a) Single degree of freedom model is considered.

b) The viscous damping is considered in this model.

c) Only cutting forces are considered in this model.

d) Sharp tool is considered.

e) The tool vibration is considered only in y (feed) direction.

A math model of orthogonal turning process (SDoF) having a flexible tool and rigid work piece is given in figure 5.1. In The model various forces acting on the physical system like the inertia force, damping force, spring force and the cutting force. But we consider viscous damping in this model. The magnitude of material (internal) damping is usually very small, Hence material damping is not considered in this model.

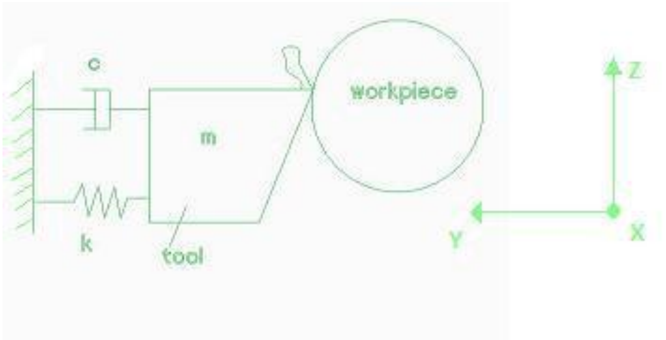


Figure 5.1 SDOF orthogonal turning process

In This model we consider a sharp tool with only the cutting force acting in the system. Secondly, a contact force is added to the cutting force side in the model which acts due to the wear of the tool soon after the turning process begins. The tool vibration is only considered in the *y* (feed) direction due to orthogonal turning assumption. For the sharp tool consideration, the equation of motion becomes

$$m\ddot{y} + c\dot{y} + ky = F \quad (1)$$

Equation of motion for a worn tool vibrating in y-direction

$$m\ddot{y} + c\dot{y} + ky = F + Fc \quad (2)$$

Here, *F* is the cutting force in feed (*y*) direction:

$$F = Kfb[y(t\text{-}T)\text{-}y(t)] \quad (3)$$

Where [y(t-T)-y(t)] is chip variation due to tool vibration

K_f= cutting coefficient in feed direction,

b = chip width (width of cut), and

T = time delay between current time and previous time

Fc is the contact force in *y*-direction, which is proportional to the total volume of displaced material V

$$Fc = KspV \quad (4)$$

Where *Ksp* is the proportionality coefficient

$$V = -\frac{bl^2\dot{y}}{2v} \quad (5)$$

where *lw* = tool flank wear length

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 13 (2018) pp. 11069-11076

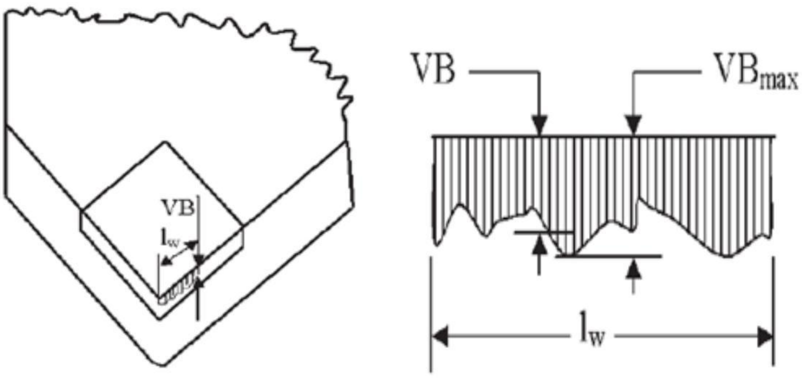


Figure 5.2 (a) Flank wears on a turning tool**(b)** Flank wear profile

The flank wear on the tool is responsible for the contact force between the tool and workpiece. Figure 5.2 (a) depicts the location of flank wear on a turning tool and figure 5.2 (b) shows detailed flank wear profile where VB is the average flank wear width, VBmax is maximum peak land width and *lw* is flank wear length/flat. The flank wear length (*lw*) is very critical in positive damping in the occurrence of chatter vibrations as explained by Tlusty (1999). Finally, the contact force can be derived from equations (4) and (5) as:

$$Fc = -\frac{Ksp\, bl^2 \dot{y}}{2v} \quad (6)$$

Equations (1) and (2) represent the equations of motion of an orthogonal turning process by considering a very sharp tool and worn tool respectively. They will be utilized to analyze the stability of the turning process for the sharp and worn tool cases. Equations (3) and (6) represent the cutting force and the contact force respectively. The stability conditions of the turning process will vary significantly when the contact force is added to the cutting force of the system which will be studied when the stability analysis is carried out.

Stability analysis by considering a sharp tool

Substituting equation (3) into equation (1) and dividing by *m* gives:

$$\ddot{y} + \frac{c}{m}\dot{y} + \frac{k}{m}y = \frac{KfB}{k}\frac{k}{m}[y(t-T) - y(t) \quad (7)$$

Applying Laplace transform and using relations

$\omega_n^2 = \frac{k}{m}$, $\frac{c}{m} = 2\,\xi\omega_n$ and assuming $\varphi = \frac{k_f\, b}{k}$

$$S^2 + 2\,\xi\omega_n\, S + \omega_n^2 = \varphi\ \omega_n^2\,(e^{-ST} - 1) \quad (8)$$

From equation (8), the transfer function of the system with a sharp tool can be obtained by derivation from differential equation

$$\Gamma_{(s)} = \frac{1}{s^2 + 2\,\xi\omega_n + \omega_n^2} \quad (9)$$

Substituting *s* = *j*ω into equation (9), where ω is the chatter vibration frequency, the real *G*(ω) and imaginary parts *H*(ω) of the transfer function are found as

$$G(\omega) = \frac{\omega_n^2 - \omega^2}{R(\omega)}$$

$$H(\omega) = -\frac{2\,\xi\omega_n\,\omega}{R(\omega)}$$

$$\text{Where } R(\omega) = \omega_n^2 - \omega^{2^{\,2}} + 2\,\xi\omega_n{}^{2} + \omega^2 \quad (10)$$

ω_n = natural frequency of the system, and ω = frequency of chatter vibration.

The limiting width of cut at which turning process switches from stable to unstable can be found by a relation

$$b_{Lim} = -\frac{1}{2\,k_f\, G(\omega)} \quad (11)$$

The spindle period (*T*) and phase shift (θ) can be obtained

$$T = \frac{(2n\pi + \theta)}{\omega},\ \theta = 3\pi + 2\,\Psi \quad (12)$$

The spindle speed can be obtained

$$N = \frac{60}{T} \quad (13)$$

Equations (11), (12) and (13) can be used to produce the so called stability chart showing the relationship between the limiting width of cut ($b_{\lim}$) and spindle speed (N) for the turning operation. The stability chart distinguishes regions of stable (chatter-free) and unstable cutting operation for different combinations of width of cut and spindle speed. By selecting specific combinations of width of cut and spindle speed, chatter vibrations can be avoided to achieve a stable turning process throughout. Table no. 5.1 shows the physical and model parameters of the tool

Table 5.1 Physical and modal parameters of the tool

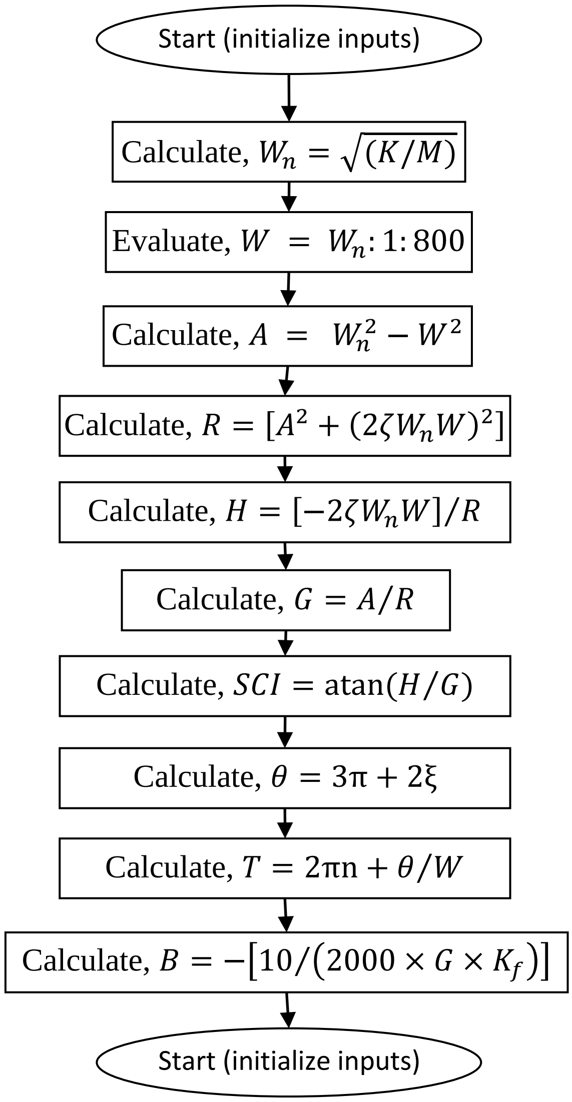
Mass m (kg)	Damping coefficient c (kg/s)	Stiffness k (N/m)	Cutting coefficient K_f (N/m^2)	Damping ratio ξ	Natural frequency F_n (Hz)
50	$2x10^3$	$2x10^7$	$2x10^9$	0.026	119

Tool wear prediction

In order to study the effect of chatter vibrations on tool wear analytically, it is imperative to generate a tool wear equation with the help of which this relationship can be established. It is also required that this equation should be able to predict tool wear at or above the stability border on the stability chart, so that tool wear can be predicted soon after the process becomes unstable. A tool wear equation can be derived from equation (11) and after some mathematical manipulation

$$I_w = \sqrt{\frac{2mv}{k_{sp}\, b}\left(\sqrt{\frac{[-2k_f(\omega_n^2-\omega^2)b_{Lim} - (\omega_n^2-\omega^2)^2]}{\omega^2}} - 2\xi\omega_n\right)} \quad (14)$$

Tool-wear prediction in the presence of chatter vibrations (unstable cutting) can be possible by using equation (14). It predicts tool wear length at and above the stability limit for an orthogonal turning process. The tool wear equation (14) predicts the tool wear rate in the presence of chatter by considering mainly the dynamics and the contact mechanism of the turning process. Flow chart on which programming is made is given below and we made different programme for Single stability lob diagram,Two Stability Lob Diagrams (SLD), Multi Stability Lob Diagrams (SLD), Single Stability Lob Diagrams (SLD), Two Stability Lob Diagrams (SLD), Multi Stability Lob Diagrams (SLD), tool wear length&damped system.



Flow chart for Single Stability Lob Diagram (SLD)

RESULTS AND DISCUSSION

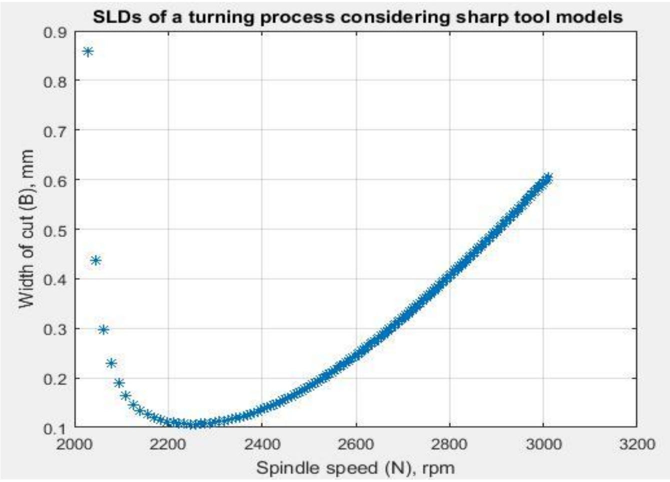
$\omega_n = 632.45$ rad/s	$\omega_n = 747.70$ rad/s
1. Starting spindle speed N = 2029.42 rpm	1. Starting spindle speed N = 2396.25 rpm
2. Starting width of cut blim = 0.86mm	2. Starting width of cut blim = 1.42 mm
3. Stable limiting width of cut blim = 0.10 mm at ω = 649 rad/sec i.e. N = 2246.5 rpm	3. Stable limiting width of cut blim = 0.15 mm at ω = 771.5 rad/sec i.e. N = 2682 rpm

The effect of varying spindle speed on width of cut was observed at different frequencies.

The effect of chatter frequency on tool wear was also observed.

First SLD at chatter frequency (ω) = 632.45rad/secwhich is a resonance frequency and natural

CASE1

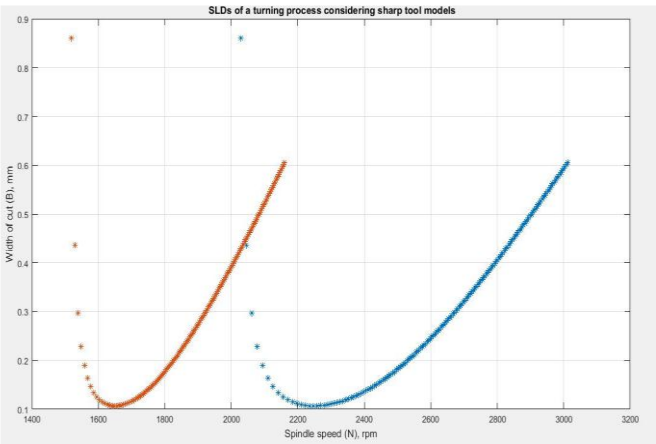


Single SLD of a turning process considering sharp tool models

Frequency (ω_n) is also 632.45 rad/sec. At this frequency Spindle speed (N) is 2029.42 rpm and starting width of cut (b) is 0.86 mm

when n = 1 we concluded that chattering in turning will be above the stability lob and stable turning process will be below the stability lob

Case 2

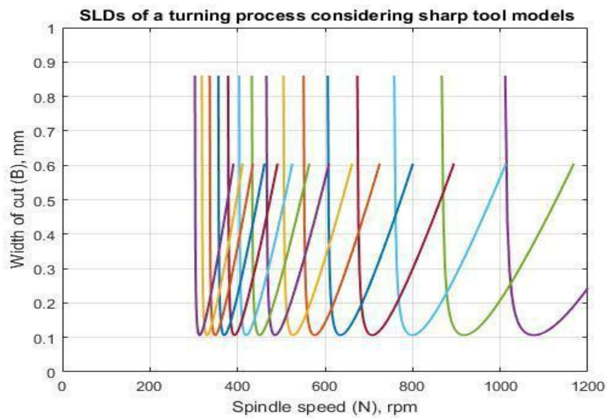


Two SLDs of a turning process considering sharp tool models

For second SLD, in equation (1) n= 2

Now at the natural frequency(ω_n) = 632.45 rad/sec, the Spindle speed (N) is 1519.61 rpm and starting width of cut (b) is same as previous concluded that chattering in turning will be above the stability lob and stable turning process will be below the stability lob

Case 3

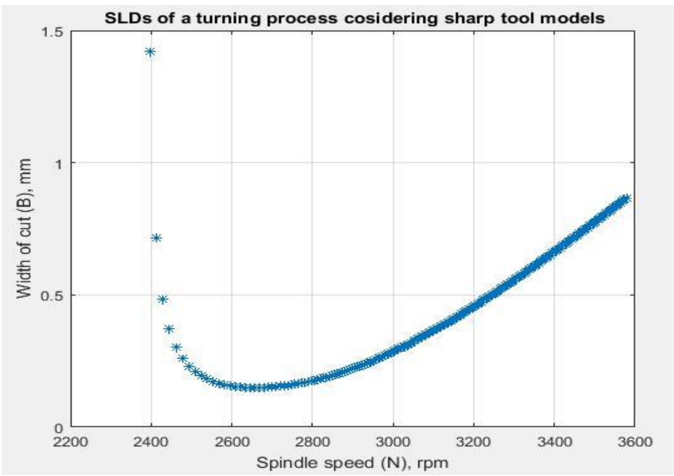


SLDs of a turning process considering sharp tool

For multiple SLDs, in equation (12), n = 18

The width of cut and spindle speed combinations below the stability lobes result in a stable turning process and above the lobes result in chatter. If a tangent line is drawn through the bottom of all the lobes, it gives the critical minimum width of cut around 0.106 mm for the sharp tool. If the width of cut is kept below these limits, a stable operation is guaranteed at all spindle speeds during turning

Case 4

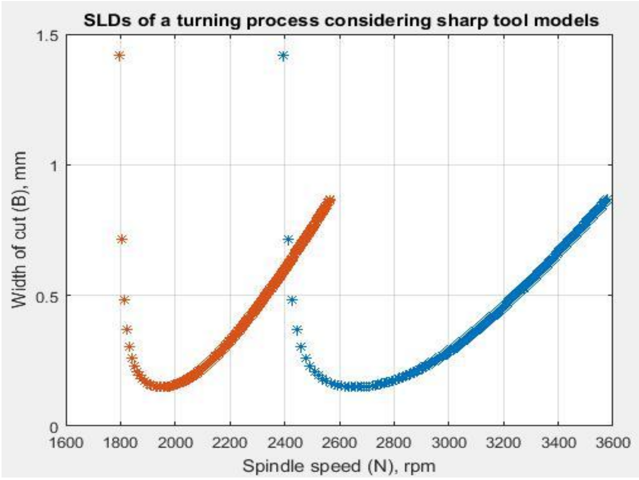


International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 13 (2018) pp. 11069-11076

Single SLD of a turning process considering sharp tool models

First SLD at chatter frequency (ω) = 747.70 rad/sec which is a resonance frequency and natural frequency (ω_n) is also 747.70 rad/sec. At this frequency Spindle speed (N) is 2396.25 rpm and starting width of cut (b) is 1.42 mm.At this frequency limiting width of cut (b_{lim}) is 0.15 mm.

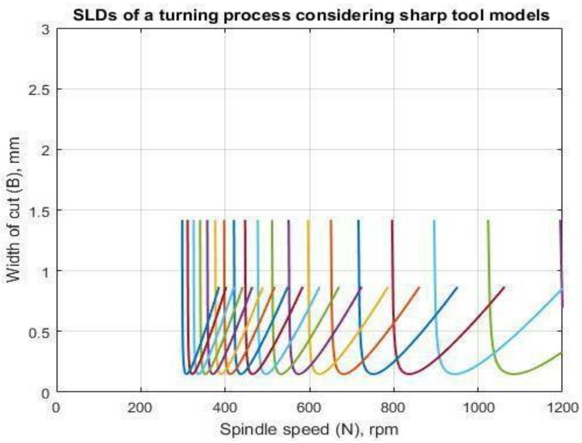
Case 5



By equation 12 and 13Put n= 2 ,

Now at the natural frequency(ω_n) = 747.70 rad/sec, the Spindle speed (N) is 1794.72 rpm and starting width of cut (b) is same as concluded that chattering in turning will be above the stability lob and stable turning process will be below the stability lob

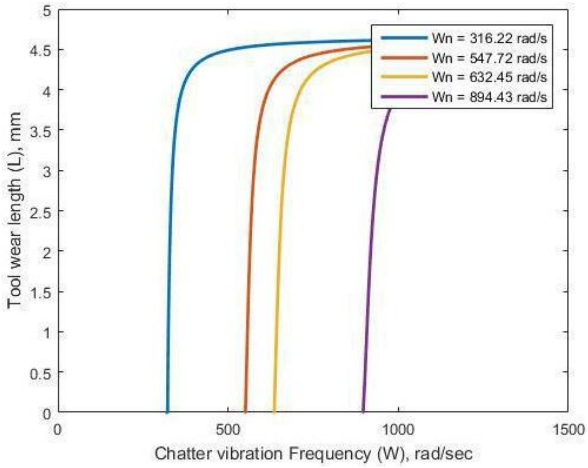
Case 6



From eqn 12 put n = 22 we get

The width of cut and spindle speed combinations below the stability lobes result in a stable turning process and above the lobes result in chatter. If a tangent line is drawn through the bottom of all the lobes, it gives the critical minimum width of cut around 0.15 mm for the sharp tool. If the width of cut is kept below these limits, a stable operation is guaranteed at all spindle speeds during turning.

Case 7



Tool wear (l_w) versus chatter vibration frequency (ω) plot for different values of natural frequencies (ω_n)

Tool wear lengths were obtained by varying chatter vibration frequencies close to the natural frequency of the system. It can be seen that the tool wears very rapidly when chatter starts to occur close to the first natural frequency of the system. The same process is repeated for different natural frequencies of the system to see the effect of the natural frequency on the tool wear. It was found that by increasing the natural frequency of the system, tool wear and tool wear rate decreases.

EXPERIMENTAL VALIDATION

Experimental validation is necessary to simulate the results of the analytical models presented in this chapter. Orthogonal and normal turning experiments are most common metal cutting operation in the manufacturing industry.

Analytical results	Experimental results (Siddhpura, M. & Paurobally, R.)
Stable limiting width of cut b_{lim} = 0.10 mm at ω = 649 rad/sec	Stable limiting width of cut b_{lim} = 0.10 mm at ω = 649 rad/sec
Stable limiting width of cut b_{lim} = 0.15 mm at ω = 747 rad/sec	Stable limiting width of cut b_{lim} = 0.10 mm at ω = 747 rad/sec
The initial tool wear rate is very high up to 4 mm of the tool wear length	The initial tool wear rate is very high up to 3 mm of the tool wear length

CONCLUSION AND FUTURE WORK

The stability of an SDoF orthogonal turning process has been analyzed by considering a sharp tool in the SDoF model. The stability limit of sharp tool case predicted by the SDoF model was found to be 0.1 mm and 0.15 mm at two different frequencies 632.45 rad/sec and 747.70 rad/sec respectively, which is obtained by programming. From the SLDs in annexure I to VI, below the stability lobes result in a stable turning process and above the lobes result in chattering.

It is observed from annexure 7 and figure 3.9 that when chatter vibrations start to occur, the initial tool wear rate is very high up to 4 mm of the tool wear length (or width of cut) during which the chances of tool breakage is high as well. On comparing the analytical results with experimental results, the difference of 1 mm in tool wear rate is obtained.

Future scope of above work that The tool wear prediction in the presence of chatter was carried out by considering mainly the dynamics mechanism and sharp tool for turning process in this thesis. There is future scope of including thermo mechanical properties in the SDoF model for tool wear predictions and by considering worn tool by programming.

REFERENCES

[1] Adam A. Cardi , Hiram A. Firpi , Matthew T. Bement , Steven Y. Liang. 2008, "Workpiece dynamic analysis and prediction during chatter of turning process" Mechanical systems and signal processing 22, pp. 1481–1494.

[2] Altintas, Y. & Weck, M. 2004, "Chatter stability of metal cutting and grinding", CIRP Annals – Manufacturing technology, Vol. 53, No. 2, pp. 619-642.

[3] Altintas, Y. 2000, Manufacturing automation, Cambridge university press, Cambridge. Bason E. Clancy, Yung C. Shin. 2002, "A comprehensive chatter prediction model for face turning operation including tool wear effect" International journal of machine tools & manufacture 42, pp. 1035–1044.

[4] Birkhoff, G. & Rota, G.-C. 1978, Ordinary differential equations, John Wiley & Sons, New York.

[5] Budak, E. & Tunc, L. 2010, "Identification and modeling of process damping in turning and milling using a new approach", CIRP Annals-Manufacturing technology.

[6] Chen, C. K. & Tsao, Y. M. 2006, "A stability analysis of regenerative chatter in turning process without using tailstock", The International journal of advanced manufacturing technology, Vol. 29, No. 7, pp. 648-654.

[7] Chiou, R. Y. & Liang, S. Y. 1998, "Chatter stability of a slender cutting tool in turning with tool wear effect", International journal of machine tools and manufacture, Vol. 38, No. 4, pp. 315-327.

[8] Choudhury, S. K., N. N. Goudimenko and V. A. Kudinov. 1997, "On-line control of machine tool vibration in turning", International journal of machine tools & manufacture, Vol. 37, No. 6, pp. 801-811.

[9] Das, M. & Tobias, S. 1967, "The relation between the static and the dynamic cutting of metals", International journal of machine tool design and research, Vol. 7, No. 2, pp. 63-89.

[10] Dimla. D. E. Sr. 2004, " The impact of cutting conditions on cutting forces and vibration signals in turning with plane face geometry inserts", Journal of materials processing technology 155–156, pp. 1708–1715.

[11] Dombovari, Z., Barton, D. A. W., Wilson, R. E. & Stepan, G. 2011, "On the global dynamics of chatter in the orthogonal cutting model", International journal of non-linear mechanics, Vol. 46, No. 1, pp. 330-338.

[12] Elbestawi, M. A., Ismail, F., Du, R. & Ullagaddi, B.C. 1994, "Modelling machining dynamics including damping in the tool-workpiece interface", Journal of engineering for industry, Vol. 116, No. 4, pp. 435-439.

[13] Ema. S, E. Marui. 2003, "Theoretical analysis on chatter vibration in drilling and its suppression", Journal of materials processing technology 138, pp. 572–578

[14] Emad Al-Regib, Jun Ni, Soo-Hun Lee. 2003, "Programming spindle speed variation for machine tool chatter suppression", International journal of machine tools & manufacture 43, pp. 1229–1240

[15] Lee, B., Tarng, Y. & Ma, S. 1995, "Modeling of the process damping force in chatter vibration", International journal of machine tools and manufacture, Vol. 35, No. 7, pp. 951-962.

[16] Sisson, T. & Kegg, R. 1969, "An explanation of low speed chatter effects", ASME Journal of engineering for industry, Vol. 91, No. 4, pp. 951.

[17] Wang. H., S. To., C. Y. Chan, C. F. Cheung, & W.B. Lee. 2010, "A theoretical and experimental investigation of the tool-tip vibration and its influence upon surface generation in single-point diamond turning", International journal of machine tools & manufacture 50, pp. 241–252.

[18] Tobias, S. A. & Fishwick, W. 1958, "The chatter of lathe tools under orthogonal cutting conditions", Transactions of ASME, Vol. 80, pp. 1079-1088.

[19] Thomas M., Beauchamp Y., Youssef A.Y., Masounave J. 1996, " Effect of tool vibrations on surface roughness during lathe dry turning process" Computers ind. Engng, Vol. 31, No. 3/4, pp. 637 – 644.

[20] Taylor, F. 1907, "On the art of cutting metals",

Transactions of ASME, Vol. 28, pp. 31-350.

[21] Siddhpura, M. & Paurobally, R. 2012c, “A review of chatter vibration research in turning”, International journal of machine tools and manufacture, Vol. 61, pp. 27-47.

[22] Siddhpura, A. & Paurobally, R. 2012b, “A study of the effects of friction on flank wear and the role of friction in tool wear monitoring”, Australian journal of mechanical engineering, Vol. 10, No. 2, pp. 141-156,

[23] Shahadat. M. M. Z, Mizuno. T, Ishino. Y, Takasaki. M. 2015, “Active vibration isolation using negative stiffness and displacement cancellation controls: Comparison based on vibration isolation performance”, Control engineering practice 37, pp. 55–66