PREDICTION OF TOOL WEAR AND DISPLACEMENT IN VIBRATION ASSISTED FACE TURNING OF AISI 4140 STEEL

[1]Dr. M. Prakash Babu, [2]Ananda Mohan Vemula
[1,2]Associate Professor Department of Mechanical Engineering Guru Nanak Institutions Technical Campus, Hyderabad, India

Abstract: The present work shows, to anticipate the work piece displacement in face turning under dry machining condition. Present work, concentrates on the improvement in machinability during vibration assisted turning of the AISI 4140 steel has been investigated using FFT analyzer. The effect of work piece displacement due to vibration on the tool wear is examined. The axial vibration amplitudes in feed direction obviously increase with increasing the feed rate. Predicted load in Y- direction for all test conditions is observed. The correlation between tool wear and displacement due to vibration analysis is done.

***Index Terms* - Displacement, face turning, Tool wear, FFT, and vibration.**

I. INTRODUCTION

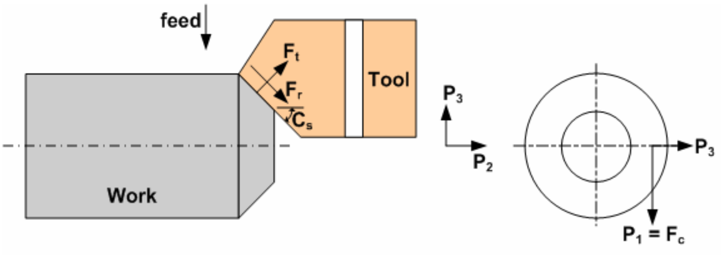
Turning operation is one of the most important and widely used material removal techniques in manufacturing industries. Several elements, like geometrical and metallurgical characteristics of the cutting tool, work piece material, and process parameters (cutting speed, feed rate, depth of cut), are taken into account when studying machining processes [1]. Among metal-cutting techniques the turning has become one of the important metal manufacturing processes and is widely used in the field of high technology for industrial application [2]. As a result of the quality characteristics of machined parts, the vibration conditions, occurring among the cutting tool, chuck, and work piece, play an important role in machining performance. Especially, the vibration of cutting tool has an undesirable effect on the machined surface, quality of the work piece and the tool wear, which lowers down the productivity and increases the cost of production. The dynamic phenomena of cutting tool induced by the interaction of an elastic system in the cutting process cause the relative displacement between tool and work piece, which generates the vibration of cutting tool. But the effects of vibrations have been paid less attention [3]. The appearance of vibrations of the cutting tools is mainly subjected to the cutting dynamics process under various cutting conditions. The dynamic phenomena of cutting tool induced by the interaction of an elastic system in the cutting process causes the relative *displacement* between tool and work piece, which generates the vibration of the cutting tool [4]. Excessive vibration can also induce the damage to the cutting tool and interfere with the feed rate, cutting speed, and cutting depth. In metal cutting as a result of the cutting motion, cutting tool wear will be influenced by cutting parameters, cutting force, and vibrations, etc. [5]. Vibrations in cutting tool due to machining condition is one of the most important technological parameters because it can significantly influence on tool wear and life, quality machined surface and cutting power. Vibration of the tool can be a good way to monitor online growth of the tool wear in turning and, therefore, it can be useful for establishing the end of tool life in these operations [6]. Research has demonstrated that the vibration produced by a machine tool gives useful information for the maintenance of its structural components. This is really significant when the goal is to monitor the cutting process in real time and to establish automatically the end of creature life. Thus, it is necessary to study on effect of cutting tool vibrations during the machining.

II. Mer and Diniz [7] carried out the experiments for correlating the variation of the tool vibration, tool wear, tool life, and surface roughness in the finish turning with the coated carbide tools. Dimla [8] described a tool wear monitoring procedure in a metal turning operation using vibration features. The monitoring procedure revealed that the vibration signals' features relate to the wear qualification of cutting tool wear. In modern machining processes [9] due to continuous demand for higher productivity and product quality asks for better understanding and mastery of the machining operation.

III. In the present work investigation primarily focuses on identifying the presence of cutting tool vibrations during face turning process at different test conditions. For this purpose an online non-contact vibration transducer i.e. Laser Doppler Vibrometer is used as a part of a novel plan of attack. The overall aim of the present work is to prepare a 3D finite element simulation based methodology to forecast the development of vibration displacement and tool wear in face turning. Specifically, the research tasks include: to provide an appropriate experimental data to prove the mathematical model of tool wear so as to look into the influence of cutting tool vibrations under the various cutting conditions.

IV. MODELLING OF VIBRATION ASSISTED FACE TURNING PROCESS

Turning is a basic operation of metal cutting and it is the most commonly used machining process. The geometry and the contracting forces of turning process are presented in Fig. 1a. Face turning operation is chosen for the present experimental investigation.



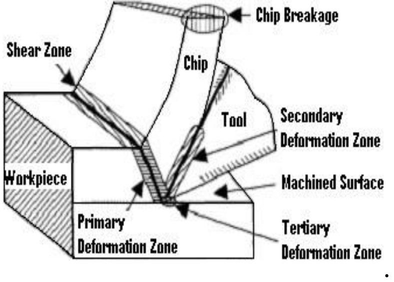


Fig.1a Oblique cutting geometry on lathe

Fig.1b Deformation zones

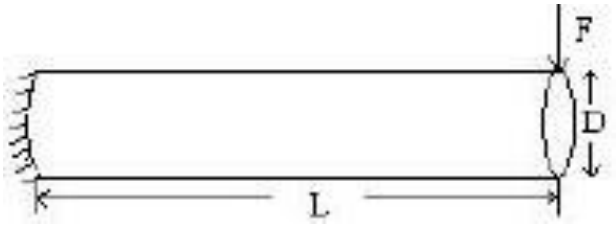


Fig. 2 Boundary and loading conditions of the cylinder [6]

As shown in Fig.1b, Deformation zones in the machining act as the sources of acoustic optic emission signals in cutting region [6]. Similar to tool wear, vibrations, particularly self- excited chatter vibrations, are very critical in machining operations. Self-excited vibrations accelerate the tool wear. Chatter can be observed almost in every machining process, and it is common in turning and milling operations. Ace of the aims of the present study is the investigation of the effects of vibration on tool wear. Machine tool chatter is a self-excited vibration caused by the interaction of chip removal process and the social organization of machine tool. The most significant type of chatter is regenerative vibration. This form of vibration usually occurs when a favorable phase relationship develops between the inside and the outer modulation, caused by vibration during two consecutive tooth passes.

In an attempt to further simplify the deflection calculation, the following analysis is performed. The maximum deflection could be found using Laser Doppler Vibrometer (LDV). The boundary and loading condition shown in Fig. 2 in which the applied power (F) can be calculated by using the following equation:

$$F = K.q \qquad (1)$$

Where K - Stiffness (N/mm) and
q - Displacement (mm) measured with LDV

If the condition of the work piece is assumed to be a cylinder the stiffness can be obtained from simplified equation.

$$K = 3EI / L^3 \qquad (2)$$

Where $E = \pi D^4 / 64$
$q = FL^3 / 3EI$
I - moment of inertia
D -Diameter
L - Length of the cylinder
E - Elastic modulus

V. MODELING OF TOOL WEAR BASED ON DISPLACEMENT DUE TO VIBRATION

As a general rule, forces and power consumption increase with increasing workpiece hardness. In the case of steel and cast iron, empirical relationships between hardness and specific power consumption (E_{sp}) or cutting force can be stated in terms of the E_{sp} value. Kronenberg [6] has found the following approximate relationships:

For steel:

$$E_{sp} \square (4.26). \sqrt{H(85-\gamma_n)} \qquad (3)$$

$$E_{sp} = F/A \qquad (4)$$

Hardness can be calculated from equation given below

$$H = \frac{F^2}{A^2.(4.26)^2(85-\gamma)} \qquad (5)$$

where cutting force (F), metal removal factor K_n (or specific power consumption, E_{sp}), depth of cut (d) , feed per revolution (f), A= (depth of cut).(Feed per revolution) = $d.f$,$\square_n$ □ rake angle, and C_F is a constant whose value depends on the material being cut and the true rake angle of the tool where x and y are exponents. The variance in the hardness of material, feed rate and depth cut is the other parameters affecting surface finish and tool wear. Flank wear (VB) can be derived from experimental data by using the following relations.

$$VB=C.H^{a}.\gamma^{n}_{n}.v^{x}.f^{y}.L^{b} \tag{6}$$

Where v is cutting speed (m/min), t machining time (min), L is the length of the cut (mm) and n, x, y, a,b, p, z are exponents.

VI. EXPERIMENTATION

The cutting parameters are chosen according to the tool supplier's recommendation for the instrument and work piece combinations. Cutting tests are conducted at dry machining conditions as per the Table 1. Cutting speed and feed rates are chosen based on the tool manufacturer's (Sandvik) recommendations for work-piece material and tool combination.

Table 1 Test conditions for experimentation

Oblique cutting parameters: Rake angle (°): -5, Clearance angle (°): 5, Flank face length (mm): 0.75, Rake face length (mm): 1 Machine: PSG Lathe, PSG India, Specifications: Specification of PSG lathe as follows: Type of Bed: Straight, Single V, Length of Bed: 2.1 m, Swing over the Bed: 21 cm, Swing over the Carriage: 14 cm, Length between centers: 96 cm, Variable Spindle speed: 63-1250 RPM, Motor Capacity: 10 H.P., Tool post: Square headed Chuck type: Four Jaw and make PSG India.		
Cutting speed (N rpm)	Feed rate (mm/rev)	Depth of cut (mm)
538	**0.08** **0.4** **0.8**	**0.5** **0.8** **1.5**
836	**0.08** **0.4** **0.8**	**0.5** **0.8** **1.5**
1135	**0.08** **0.4** **0.8**	**0.5** **0.8** **1.5**
Work piece material AISI 4140 steel of size (Ø 80 x 150mm)	Carbide Tool Properties: DNMA432 (uncoated, WC as base cloth), Tool holder: DDJNR.	
Coefficient of thermal expansion (µm /m°C) 12.3(at 20°C) Density (g/cm^3) 7.8 Poisson's ratio 0.3 Specific heat (J/kg/°C) 473 Thermal conductivity (W/m°C) 42.7 Young's modulus (GPa) 210	Coefficient of thermal expansion (µm/m°C) 4.7 (at 20 °C) 4.9 (at 1000 °C) Density (g/cm^3) 15 Poisson's Ratio 0.2 Specific heat (J/kg/°C) 203 Thermal conductivity (W/m°C) 46 Young's Modulus (GPa) 800	

VII. EXPERIMENTAL STUDIES AND TOOL WEAR – DISPLACEMENT CORRELATION:

Experiments are conducted on PSG-124 lathe at constant cutting conditions. This machine has both auto feed and variable spindle speed capabilities. Experimental set-up on lathe machine is presented in Fig.3. A Kistler® 9272 4-component dynamometer with a multi-channel analyzer used for cutting force acquisition. A PolyTech 100V Laser Doppler Vibrometer with data acquisition scheme is maintained at a constant distance from the machining zone to measure the shift during cutting procedure. The laser is concentrated along the rotating work piece while machining is going along.

Fig. 3 Experimental setup used for Face Turing

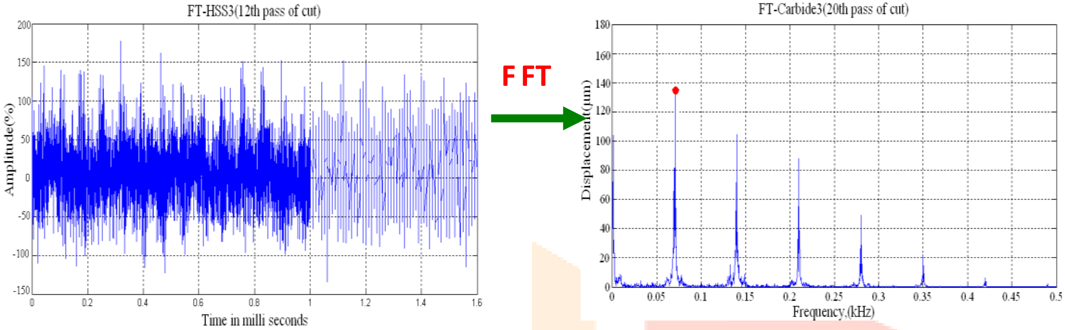
The spectrum graph provides more info about the machining process than the waveform graph. The vibration parameter used to study the vibration signal in frequency domain is displacement. All the time domain signals in the present work are filtered using a 0- 500Hz band pass filter and signal processing involves signal blocks of 4000 data points collected over a sampling interval 500 milliseconds. Before each cut, the worn edge was removed from a new one to avoid any influence of wear.

CORRELATION BETWEEN TOOL WEAR AND DISPLACEMENT DUE TO VIBRATION:

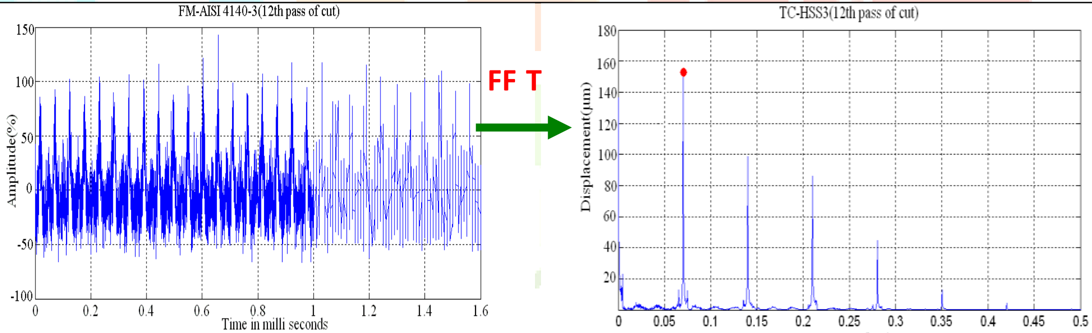
The relationship between vibration amplitude and flank wear can be explicated as follows. It is known fact that the friction between the creature and the work piece is less when the tool is new and accordingly the amplitude of vibration will also be down. As the duration of the work piece decreases, the hardness of the workpiece increases and a comparable increase in oscillation amplitude is recorded. Further increase in oscillation amplitude is because of the increasing clash between the workpiece and cutting tool which is due to increase in tool wear. Thenceforth, a second peak appears as the tool reaches and passes its wear limits, after which the friction decreases and vibration amplitude correspondingly drops drastically as the instrument breaks. The vibration is measured in the feed direction from this direction has more dominant signals than other two directions. Here, the displacement is considered as the vibration parameter in the present experimental analysis.

Test condition 1: Cutting speed 538 RPM, feed at 0.08 mm/rev, depth of cut 0.5 mm

Time domain analysis of signal (waveform graph)	Response of dynamic signal in frequency domain (spectrograph)



Test condition 2: Cutting speed 836 rpm, feed at 0.4 mm/rev, depth of cut 1.5 mm



Test condition 3: Cutting speed 1135rpm, feed at 0.8mm/rev, depth of cut 0.8 mm

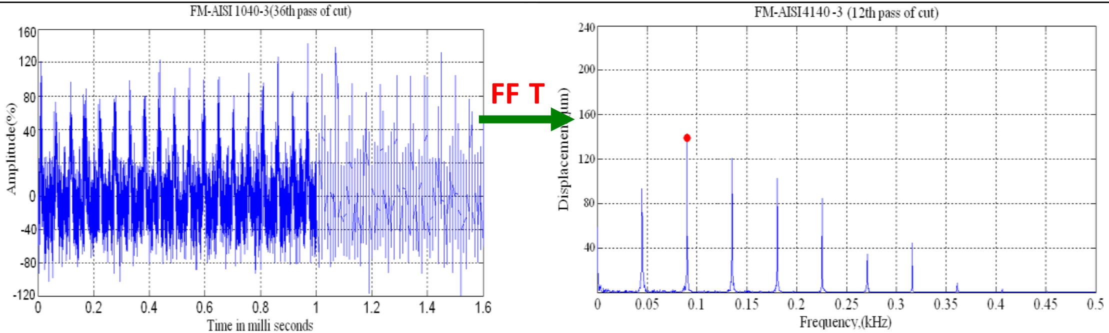


Fig. 4 Time and frequency domain spectrograph for different test conditions

The peak amplitude varies from 5□*m* to 150 □*m* depending on the severity of the chatter and cutting speed. As per ISO 2372 (10816) for vibration severity standards, displacements in rotating object up to 20 □*m* do not have any effect on tool flank wear. Tool flank wear is found to be affected by the measured displacements in the range between 20 □*m* to 60 □*m*. A displacement value beyond 60 □*m* is not acceptable. The results presented in Fig.4 justify this standard. Any displacement beyond this value is showing excessive vibration which is deteriorating the work piece surface and reducing the tool life. In all test conditions for different variations, displacements of target vibrating objects are easily perceived by analyzing the acoustic optic emission signal at different stages of tool wear.

VIII. RESULTS AND DISCUSSION

To investigate the effect of displacement due to vibration on tool wear an experimental approach is presented. In face turning process, the vibration stability of cutting tool affects the quality of the machined surface. The status of feed rate corresponds to the amount of resistance force acting on the edge of cutting tool. This resistance force for the work piece is regarded as the cutting force. The increase in the feed rate causes the increase of the resistance force in the cutting feed direction. A further increase in the feed rate causes the excited vibration appearance to appear more discontinuous chip. In the turning process, the resistance force acting on the cutting tool is mainly generated by the status of feed rate and depth of cut. Kistler 9272 dynamometer is employed to measure the cutting forces in the experimental investigation but force values intentionally not included in the results Table 2.

Table 2 Experimental values (Turning)

Test condition	Cutting Speed (N)	Feed rate (f)	Depth of cut (d)	Hardness	Displacement □m	Flank wear,VB (mm)	Machining Time (min)
TC1- 1	538	0.08	0.5	152.5	12	0.08	8.22
TC 1-2	538	0.4	0.8	158.5	23	0.17	25.43
TC 1-3	538	0.8	1.5	167	34.25	0.27	42.15
TC 2-1	836	0.08	0.8	153	22	0.10	6.35
TC 2-2	836	0.4	1.5	160	49	0.32	13.43
TC 2-3	836	0.8	0.5	162	50	0.35	14.33
TC 3-1	1135	0.08	1.5	159	35	0.22	3.10
TC 3-2	1135	0.4	0.5	162	46	0.33	3.08
TC 3-3	1135	0.8	0.8	170	70	0.44	6.02

In particular, the effects of change of depth of cut at constant cutting speed is studied which defines the onset of instability. Also, the effect of cutting speed on the stability is investigated.

IX. REFERENCES

[1] A. Attanasio, E.Ceretti, C.Giardini and C.Cappellini., Tool Wear in Cutting Operations: Experimental Analysis and Analytical Models, Journal of Manufacturing Science and Engineering, Transactions of the ASME, 135, (2013) 051012-1-11.

[2] Chih-Cherng Chen, Nun-Ming Liu, Ko-Ta Chiang and Hua-Lun Chen., The use of D- optimal design for modelling and analyzing the vibration and surface roughness in the precision turning with a diamond cutting tool, International Journal of Advanced Manufacturing Technology,54, (2011) 465–478.

[3] Ning Fang, P.Srinivasa Pai and S.Moquea., Effect of tool edge wear on cutting forces and vibrations in high-speed finish machining of Inconel 718: an experimental study and wavelet transform analysis, International Journal of Advanced Manufacturing Technology, 52, (2011) 65–77.

[4] Tounsi N, Otho A., Identification of machine-tool–workpiece system dynamics, International Journal of Advanced Manufacturing Technology, 40, (2000) 1367–1384.

[5] Chih-Cherng Chen, Nun-Ming Liu, Ko-Ta Chiang and Hua-Lun Chen., Experimental investigation of tool vibration and surface roughness in the precision end-milling process using the singular spectrum analysis, International Journal of Advanced Manufacturing Technology,63, (2012) 797–815.

[6] Balla Srinivasa Prasad, M. M. M. Sarcar and B. Satish Ben., Development of a system for monitoring tool condition using acousto-optic emission signal in face turning—an experimental approach, International Journal of Advanced Manufacturing Technology,51, (2010) 57–67.

[7] Mer A and Diniz AE., Correlating tool wear, tool life, surface roughness and tool vibration in finish turning with coated carbide tools, Wear,173, (1994) 137–144.

[8] Dimla DE., The correlation of vibration signal features to cutting tool wear in a metal turning operation, International Journal of Advanced Manufacturing Technology, 19, (2002) 705–713.

[9] A. G. Mamalis, J. Kundrák, A. Markopoulos and D. E. Manolakos., On the finite element modelling of high speed hard turning, International Journal of Advanced Manufacturing Technology,38, pp. (2008) 441–446.