Control of Cutting Tool Vibration in CNC using Damping Pad

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***Abstract* - Machining is a complex process in which many variables can deleterious the desired results. Among them, cutting tool vibration is the most critical phenomenon which influences dimensional precision of the components machined, functional behavior of the machine tools and life of the cutting tool. In a machining operation, the cutting tool vibrations are mainly influenced by cutting parameters like cutting speed, depth of cut and tool feed rate. In this work, the cutting tool vibrations are controlled using a damping pad made of Neoprene. Experiments were conducted on CNC where the tool holder is supported with and without damping pad. The cutting tool vibration signals were collected through a data acquisition system supported by LabVIEW software. To increase the buoyancy and reliability of the experiments, a full factorial experimental design was used. Experimental data collected were tested with analysis of variance (ANOVA) to understand the influences of the cutting parameters. Empirical models have been developed using analysis of variance (ANOVA). Experimental studies and data analysis have been performed to validate the proposed damping system. The onsite tests show that the proposed system reduces the vibration of cutting tool to a greater extend.**

Index Terms - Neoprene, LabVIEW, ANOVA

I. INTRODUCTION

The modern trend of machine tool development is required to produce precise, accurate and reliable product which are gradually becoming more prominent features. In a machining operation, vibration is frequent problem, which affects the machining performance and in particular, the surface finish and tool life. Severe vibration occurs in the machining environment due to a dynamic motion between the cutting tool and the work piece. In all the cutting operations like turning, boring and milling, vibrations are induced due to the deformation of the work piece, machine structure and cutting tool. In a machining operation, forced vibration and self-excited vibration are identified as machining vibrations.

Forced vibration is a result of certain periodical forces that exist within the machine, bad gear such as drives, misalignment, and unbalanced machine tool components, etc. Self-excited vibration is caused by the interaction of the chip removal process and the structure of the machine tool, which results in disturbance in the cutting zone. The self-excited vibration affects the production capacity, reliability and machining surface quality. Today, the standard procedure adopted to avoid vibration during machining is by careful planning of the cutting parameters and damping of cutting tool. The methods adopted to reduce vibration are based on experience as well as trial and error to obtain suitable cutting parameters for each cutting operation.

Damping is the capacity of a mechanical system to reduce the intensity of a vibratory process. The damping capacity can be due to interactions with outside systems or due to internal performance- related interactions. The damping effect for a vibratory process is achieved by transforming (dissipating) mechanical energy of the vibratory motion into other types of energy, most frequently heat, which can be evacuated from the system. Passive damping is now the major means of suppressing unwanted vibrations. The primary effect of increased damping in a structure is a reduction of vibration amplitudes at resonances with corresponding decreases in stresses, displacements, fatigue and sound radiation. Designed in- passive damping for any structure is usually based on one of four damping mechanisms: viscoelastic materials, viscous fluids, magnetics or passive piezoelectric (Johnson, 1995).

Based on the literature survey, approximately 85 percent of the passive damping treatments in actual applications are based on viscoelastic materials, with viscous devices being the second most actively used (the use of viscous devices is greater for isolation and shock). In the present work attempt has been made to predict and suppressing the vibration level of cutting tool in CNC lathe, by using passive damping pad of viscoelastic material of neoprene. The study is extended to analyse the influence of cutting parameters on the tool vibration during machining. The results obtained have shown the effectiveness of the proposed solution that have been analysed and discussed in detail.

II. EXPERIMENTATION

The experimental setup is shown in Figure 1. It includes a CNC -Galaxy –MIDAS-0 turning center, a CCGT-09T30FL (Taegu Tec) turning insert, tool holder SCLC L2020 K09 T3(Taegu Tec), a work piece (Al 6063 aluminum, Diameter 38 mm x 70mm length) without any cutting fluid. The tool is instrumented with two accelerometers (Bruel & Kjaer 9.88mV/g- type 4517). The accelerometers signals are taken to NI PXI 1042 – Q Data Acquisition Card system using LabVIEW software.

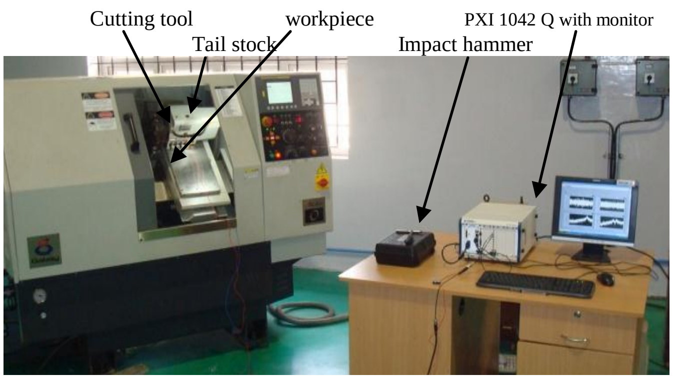

Fig 1. Experimental setup

A. Hardware system

Vibration signals are important for monitoring tool condition in turning process. Accelerometers were mounted in the cutting tool, one in the tangential direction of the tool holder and the other one was placed in the axial direction of the tool holder for measuring vibration amplitude in terms of accelerations (g-levels). A computer code has been developed in LabVIEW for data acquisition, data storage and display. Fast Fourier Transform (FFT) computation algorithm was included in the computer program to extract the vibration amplitude in the time and frequency domain, which will be explained in software development section.

B. Software system

Main objective of the research work is to monitor the vibration level of cutting tool. So it is assumed that the condition of the machine and its components is good in all other aspects such as foundation of the machine, rigidity of the machine components (such as bed, spindle, tail stock etc.) and so on. The simplest vibration analysis is conducted through collecting the "overall" vibration amplitude Root Mean Square (RMS) value and plotting the vibration data in time domain and frequency domain. The "overall" signal represents the total energy content of all vibration sources at all frequencies.

C. *Integration and testing of the data acquisition system*

The Integration and testing of the data acquisition system is shown in figure 1. When tested in a machining work piece, the sensor was protected to prevent any interference caused due to machining chips.

1) Modal Analysis – With and without damping pad

Any physical system can vibrate, the frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and can be determined using modal analysis. The free vibration tests were carried out for the given cutting tool without any damping pad. In the free vibration analysis test, an impact hammer (PCB-086C03) was used to excite the cutting tool. An accelerometer was mounted on the tool holder and interfaced with a data acquisition card and LabVIEW software to record the response of the cutting tool in time and frequency domains. The impact pulse indicating the magnitude of input force was generated by the impact hammer. The frequency domain response was obtained by using signal analyser available in sound and vibration toolkit of Lab VIEW. The response of the tool holder captured in time and frequency domains as shown in Figure 2.

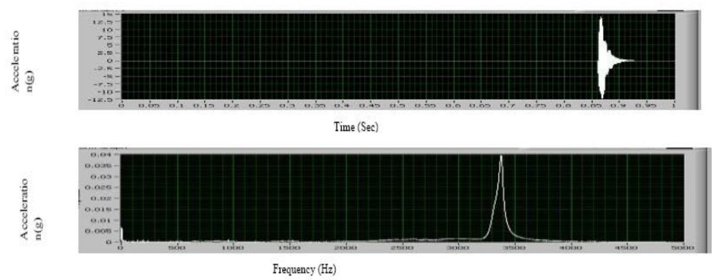

Fig 2. Vibration signal for response of the accelerometer of free vibration test (without damping pad).

From the Figure 2, it is evident that, the fundamental natural frequency of the tool is about 3.4 kHz, acceleration of 12.5g and it takes about 0.95 seconds to settle down. The damping ratio is calculated using Bandwidth method and the value is obtained as 0.0149. The free vibration tests were carried out for the given cutting tool using damping pad made of neoprene. The experimental modal analysis was repeated for the damping condition. The response of the cutting tool is shown in Figure 3, from the figure, the fundamental natural frequency of the cutting tool were found to be about 2.150 kHz, and it takes about 0.4 seconds to settle down. The damping ratio was calculated as 0.06976.

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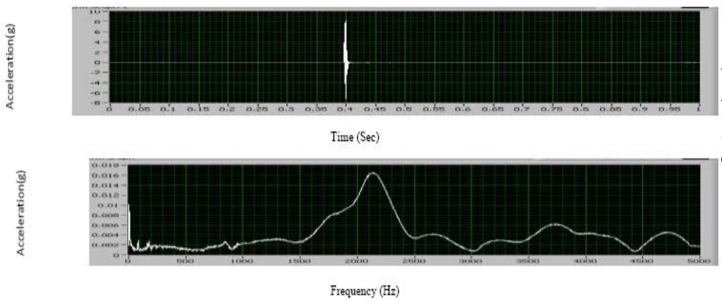

Fig. 3. Vibration signals for response of the accelerometer of free vibration test (with damping pad).

2) Dynamic Analysis - without damping pad

The vibration analysis was done without any damping pad under actual machining conditions. In this analysis, a set of experiments were conducted with the cutting tool held in the tool holder as shown in Figure 4a. The two accelerometers mounted in both the tangential and axial directions were used to collect the vibration signals.

The LabVIEW acquires the vibration signals and stored the signals continuously frame by frame at every stage of cutting in on-line. The vibration data given in Figure 4b is obtained while turning with cutting speed of 250m/min, depth of cut of 0.5mm and feed rate of 0.1mm/rev. The dynamic response of accelerometer without any damping pad is given in table 2.

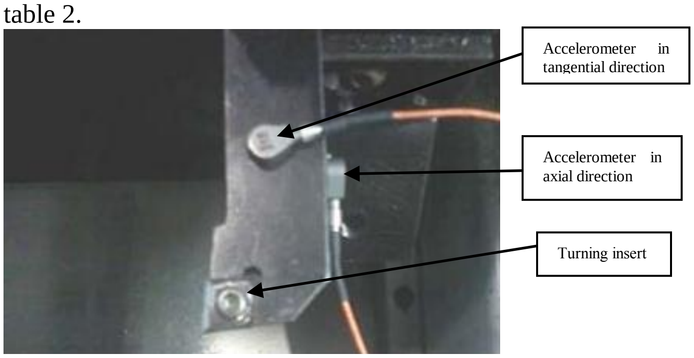

Fig 4a. Cutting tool without damping pad

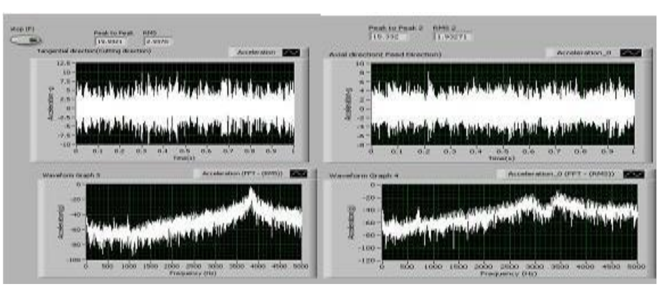

Fig 4b. Cutting tool vibration signals without damping pad

3) Dynamic Analysis with damping pad

In this set of experiments, the cutting tool is clamped with damping pad made of rubber material called neoprene is shown in Figure 5a. Same set of experiments were repeated as given in previous section and vibration signals were collected with the use of damping pad. The cutting tool vibration signals with damping pad at cutting speed of 250 m/min, depth of cut of 0.5 mm and feed rate of 0.1 mm/rev is shown in Figure 5b. The dynamic response of accelerometer with damping pads is given in Table 2.

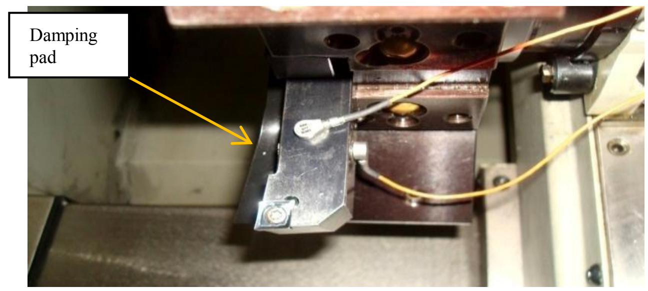

Fig 5a Cutting tool with damping pad

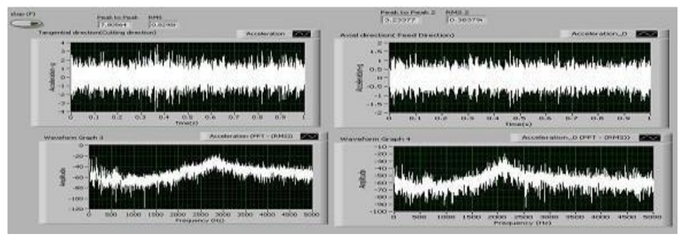

Fig 5b Cutting tool vibration signals with damping pad

III. EXPERIMENTAL DESIGN

Experimental design approach is selected for the investigations of varying three controllable parameters at three levels, since 3*k* factorial design is efficient to study the effects of two or more factors. Without loss of generality three levels of factor are referred as low, intermediate and high and levels are designed by digits 0.1 and 2. Each treatment combination in the 3*k* design is denoted by *k* digits where the first digit indicates a level of factorial *A* (cutting speed), *B* (depth of cut), indicates the level of factorial second and *C* (Feed) indicates the level of three. These factors as well as their levels identified are given in Table 1.

TABLE I
IDENTIFIED CONTROL FACTORS AND THEIR LEVELS

Variables/Parameter	Parameter Designation	Level 1	Level 2	Level 3
Cutting speed(m/min)	A	150	200	250
Depth of cut(mm)	B	0.5	0.75	1
Feed (mm/rev)	C	0.1	0.2	0.3

TABLE II
INPUT PARAMETERS AND DYNAMIC RESPONSE OF ACCELEROMETERS WITH AND WITHOUT DAMPING PAD

Expt. No	CS	DOC	FR	Amplitude of acceleration level of cutting tool , in g			
				Tangential direction		Axial direction	
				RMS		RMS	
				withoutdamping pad	with damping pad (Neoprene)	withoutdamping pad	with damping (Neoprene)
1	150	0.5	0.1	2.96	1.052	1.55	0.91
2	150	0.5	0.2	3.21	0.86	2.17	0.40
3	150	0.5	0.3	2.91	1.17	1.69	0.55
4	150	0.75	0.1	3.49	0.789	2.37	0.41
5	150	0.75	0.2	4.14	2.08	2.45	1.19
6	150	0.75	0.3	4.03	3.34	2.31	1.31
7	150	1	0.1	3.74	0.76	2.01	0.44
8	150	1	0.2	4.53	3.5	2.56	2.00
9	150	1	0.3	4.58	3.72	2.18	2.08
10	200	0.5	0.1	3.03	0.53	2.22	0.29
11	200	0.5	0.2	3.70	1.28	3.14	0.52
12	200	0.5	0.3	3.86	1.64	3.13	0.79
13	200	0.75	0.1	3.70	0.65	2.47	0.38
14	200	0.75	0.2	4.41	1.68	2.90	0.78
15	200	0.75	0.3	5.55	2.23	3.61	1.17
16	200	1	0.1	3.66	0.86	2.51	0.59
17	200	1	0.2	5.84	3.7	3.45	0.8
18	200	1	0.3	6.35	4.5	3.52	1.12
19	250	0.5	0.1	2.93	0.82	1.93	0.38
20	250	0.5	0.2	4.83	1.31	5.30	0.42
21	250	0.5	0.3	4.97	1.83	4.21	0.641
22	250	0.75	0.1	4.24	0.67	3.01	0.28
23	250	0.75	0.2	5.0	1.24	3.96	0.59
24	250	0.75	0.3	6.84	1.61	5.058	0.77
25	250	1	0.1	5.91	0.65	3.82	0.34
26	250	1	0.2	7.68	3.45	5.52	1.36
27	250	1	0.3	7.75	6.35	6.05	3.21
CS = Cutting speed in m/min				DOC = Depth of cut in mm		FR = Feed rate in mm/rev	

IV. RESULTS AND DISCUSSION

The vibration phenomenon for various cutting condition has been analysed using LabVIEW software. The plan of the experiment was developed to assess the effect of cutting speed, feed rate and depth of the cut on the cutting tool vibration. Table 2 illustrates the experimental result of vibration in both tangential and axial cutting direction. After analysis of the vibration, passive damping pad is provided below the cutting tool elements. Now the same experiment was carried out for various cutting condition and cutting tool vibration is measured and tabulated in Table 2. Figure 6 displays the comparison of vibration of cutting tool at various cutting condition in tangential direction without damping pad and with damping pad. Figure 7 displays the comparison of vibration of cutting tool at various cutting condition in axial direction without damping pad and with damping pad.

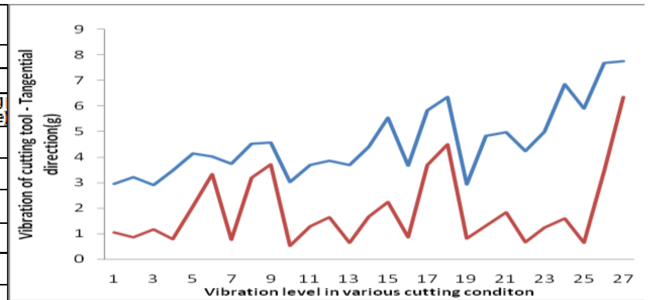

Fig 6. Vibration of tool holder in Tangential-direction (RMS)

Legend: The upper curve shows vibration signal without damping and lower curve is with damping

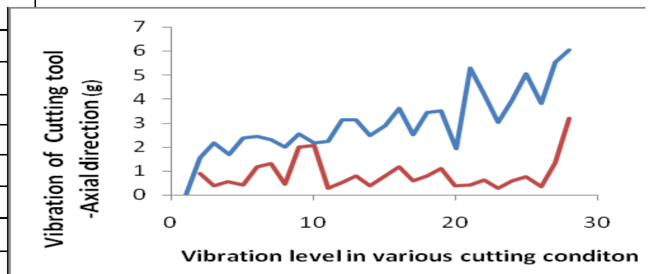

Fig 7 Vibration of tool holder in Axial-direction (RMS)

This passive damping pad dissipates energy at various cutting conditions. Due to this addition of damping material in this experiment, the vibration level is reduced to 29.3129%. One of the objectives of this study is to find the important factors and combination of factors influencing the vibration level of cutting tool using the lower the better characteristics. The experimental results were analyzed using analysis of variance (ANOVA), which is used for identifying the factors significantly affecting the performance measures. The results are analyzed with MINITAB software. The result of ANOVA analysis indicates that the depth of cut is the most influencing factor on the vibration. The percentage of contribution shows that depth of cut 38%, cutting speed contributes 35% and feed rate contributes 27% only when amplitude of acceleration level of vibration is measured. Therefore for the cutting tool vibration depth of cut was found to be the more significant parameter. According to the ANOVA response the best regression equation (1 & 2) obtained for cutting tool vibration for both tangential and axial direction:

Vibration Level (V_T) = - 3.50 + 0.0184 x1 + 3.92 x2 + 7.32 x3

Vibration Level (V_A) = - 3.34 + 0.0217 x1 + 1.40 x2 + 5.48 x3

Where *x*1 = Cutting Speed, *x*2 = Depth of cut, *x*3 = Feed rate, V_T = Vibration level in terms of acceleration g in tangential direction, V_A = Vibration level in terms of acceleration, *g* in axial direction.

V. CONCLUSIONS

In this course of study, Experiments were conducted on CNC using CCGT-0930FL carbide turning insert, machining variables such as cutting tool vibration in tangential and axial direction were measured in CNC machining processes based on the vibration signal collected through a LabVIEW data acquisition system and controlled by using Viscoelastic material (VEM) neoprene. The effect of cutting parameters such as cutting speed, depth of cut and feed rate on machining variables is evaluated. The testing result showed that the developed method was successful. Based on the current study, the following conclusions can be drawn.

- From the modal analysis the signals peaks exhibit response in a particular natural frequency range 3400 Hz without any damping pad. The natural frequencies were shifted to 2150 Hz with neoprene damping pad.
- It is observed that the natural frequency shifts away from the operating frequency thereby avoiding the resonance condition of cutting tool.
- Passive damping can provide substantial performance benefits in many kinds of structures and machines, often without significant weight or cost penalties. In all aspects of the studies performed, a significant reduction in tool vibration during machining was achieved for a CNC machining operations.
- The cutting tool damping ratio is improved from 0.0149 to 0.06976 with neoprene pad which indicates that the use of cutting tool pad helps to improve the cutting tool life.
- The vibration level in tangential and axial direction was found to be reduced by 60 % and 78.5% with neoprene damping pad.
- The method presented effectively measure and control cutting tool vibration. The goal of this research is successfully met.
- An analysis of variance (ANOVA) was made and it was found that the depth of cut (38% contribution), cutting speed (35% contribution) and Feed rate (27% contribution) has greater influence on cutting tool vibration. From the experimental results demonstrate that the depth of cut and cutting speed are the main parameters among the three controllable factors (depth of cut, cutting speed and feed rate) that influence the vibration of cutting tool in turning Al 6063 aluminum.

Further study could consider more cutting parameters, tool geometries and different work piece materials, lubricant and cooling strategy in the research to see how the factors would affect vibration level.

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