CHAPTER 3

PRELIMINARY EXPERIMENTS IN HARD TURNING

In this chapter, details of preliminary experiments conducted are reported. The objective of the preliminary work was (i) To study the wear pattern of the CBN cutting tool in hard turning and (ii) To explore the possibility of monitoring the process using vibration signals, captured in the main cutting speed direction and in the feed direction.

3.1 DETAILS OF THE EXPERIMENTAL WORK

The experiments were conducted on a Quest 8/15SP Hardinge CNC turning center of 15kW capacity. The workpiece was a 55 mm diameter cylindrical rod of about 130 mm length, made of high carbon, high chromium steel (AISI-D3, UNS No.T30403). The chemical composition of the work material was determined experimentally to be 2.12% carbon, 10.84% chromium, 0.48% silicon, 0.37% manganese, and the remaining, Iron. The workpiece was hardened by oil quenching from the temperature of 900°C and then tempered in two stages at 350°C and 250°C. The final hardness obtained was 60 HRC, and this was measured using a Rockwell hardness tester.

A CBN cutting tool insert of commercial grade DR 50 (Debeers) was used for the preliminary study. The DNMA 150408 inserts along with the DDJNL 2525 M15 tool holder, were used in the experiments. While mounting the tool, care was taken to align the tool tip along the axis of rotation of the workpiece. DR 50 has low CBN content dispersed in ceramic matrix and
since prominent constituting is ceramic, the thermal conductivity is low. This facilitates slower removal of heat from shear zone enabling relatively easier material removal. Thus the low thermal conductivity of DR 50 facilitates hard turning.

3.2 EXPERIMENTAL SET UP AND PROCEDURE

The schematic arrangement of the experimental set up in shown in Figure 3.1. The vibration measurement system consists of 8202A10 Kistler broad band accelerometers, a two channel charge amplifier, Agilent 54621A, 60 MHz Digital Storage Oscilloscope, 82357A GPIB interface card and Computer, connected as shown in the figure. The close-up view of the sensors and tool is shown in Figure 3.2.

Figure 3.1 Schematic Arrangement of the Experimental Setup
Figure 3.2 Close up view of Vibration Sensors, Tool and Workpiece

The vibration signals measured by the sensor were amplified by the charge amplifier and captured by the oscilloscope. The captured vibration signals in the feed and cutting speed direction, were discretised as 2,000 data points, and transferred to the computer using the GPIB interface for further data processing.

The hard turning experiments were carried out with a constant depth of cut of 0.1 mm and feed rate of 0.05 mm/rev. Since the hard turning is a finishing operation, generally low values of the feed and depth of cut are employed. Gaurav Bartarya et al., 2012 had suggested that the cutting feed in the range of 0.05 to 0.2 mm/rev and depth of cut not more than 0.2mm to be the ideal condition for finish hard turning process. Considering all this, the hard turning experiments were carried out with a constant depth of cut of 0.1 mm and feed rate of 0.05 mm/rev.
The generally recommended cutting speeds for hard turning of materials with hardness in the range of 60 HRC is about 100 m/min. (Mohamed Atmane et al., 2009). The high feed and depth of cut was found to adversely affect the quality of surface finish (Lalwani et al., 2008 and Dilbag singh et al., 2007). Hence, the cutting speed for the experiments was selected at three levels, which are 70, 100 and 130 m/min. Among cutting conditions, only cutting speed was varied as cutting speed is the primary factor influencing the tool wear.

During each experiment, the turning operation was interrupted periodically, and the tool wear was measured using a tool maker’s microscope. The workpiece was also unloaded and the surface roughness of the workpiece was measured, using a Taylor Hobson -Talysurf roughness tester. Experiments were continued till the tool flank wear land clearly crossed the limiting flank wear land value of 0.3 mm. The vibration signals in the cutting speed and feed directions were captured using two channel digital storage oscilloscope and transferred to the computer for further analysis.

3.3 WEAR BEHAVIOR OF THE CUTTING TOOL AT VARIOUS CUTTING SPEEDS

The value of the tool flank wear land measured at various time instants of machining for all the three cutting speeds are given in Figure 3.3.
It can be observed from the figures that the conventional three phases of tool wear, namely the initial running-in wear, the steady state wear and rapid tool wear are not clearly distinguishable. This is unique for hard turning, and is consistent with the wear behavior observed in other studies (Dawson and Thomas 2006, Mohamed Athmane Yallese et al 2009). However as expected in any metal cutting operation, the wear becomes steeper and more rapid, for higher cutting speeds. Though the different wear regions were not very clearly distinguishable, one can easily see the wear rate becoming very high as the flank wear land value crosses the 0.3 mm mark, for all the three cutting speeds. The tool life of CBN at the cutting speeds of 70 m/min, 100 m/min and 130 m/min was 70 min, 38 min and 20 min respectively.

Figure 3.4 shows the tool life for the flank wear criteria $V_B = 0.3$mm plotted as a function of cutting speed in a log - log plot. The straight line obtained shows that the tool wear behavior follows the classical Taylor’s tool
life equation of $V_cT^n = C$. The slope of the straight line in figure 3.4 indicates the $1/n$, where $n$ is the tool life index in the Taylor’s tool life equation. The parameter ‘n’ is a very rough indicator of the level of influence of the cutting speed on the tool life. The high the value of ‘n’ signifies the relatively lower influence of the cutting speed on tool life and ‘n’ is influenced by the tool material – work material combination. From figure 3.4, the value of $n$ can be computed as 0.5102. The ‘n’ values for the conventional machining of steel, using carbides or High Speed Steel (HSS) will be in the range of 0.1 to 0.2 (Boothroyd, 1975 Shaw, 2008). This high value of ‘n’ signifies the tool life varying less steeply as a function of the cutting speed in hard turning AISI D3 steel with CBN inserts, compared to the conventional turning of steel using the HSS or carbide.

![Figure 3.4 Effect of Cutting Speed on Tool Life](image)

### 3.4 EFFECT OF TOOL WEAR ON SURFACE ROUGHNESS

The experimental study is also to analyze the impact of tool wear on the quality of surface generated in hard turning. Figures 3.5, 3.6 and 3.7 show the roughness parameters $R_a$ and $R_z$, as a function of the flank wear land.
Figure 3.5 Effect of Flank Wear on Roughness at $V_C = 70\text{m/min}$

Figure 3.6 Effect of Flank Wear On Roughness at $V_C = 100\text{m/min}$
Figure 3.7 Effect of Flank Wear on Roughness at $V_C = 130 \text{m/min}$

All the three figures indicate a gradual increase in the surface roughness as the flank wear land of the tool increases. It can also be observed that, even at the point when the flank wear land was about 0.3 mm, the $Ra$ the value of the surface roughness is less than 0.7 $\mu$m for all cutting speeds. This shows that as a manufacturing process, hard turning can be employed for finish machining as an alternative to grinding. The deterioration in the surface roughness becomes very steep as the wear land crosses the critical value of 0.3 mm.
3.5 **EFFECT OF WEAR ON PRODUCTIVITY**

![Graph showing volume of material removed at different cutting speeds](image)

**Figure 3.8  Effect of Cutting Speed on Volume of Material Removed for the Flank Wear Criteria $V_B = 0.3$ mm**

On the basis of the allowable flank wear criteria $V_B = 0.3$ mm, the volume of the uncut chip removed was calculated and it is presented in Figure 3.8. For an increase in cutting speed having 70 m/min to 130 m/min, the stock removal fell by 42%. For an increase in the cutting speed from 100 m/min to 130 m/min, the material removal fell by 15.5%. Though a higher cutting speed can lead to faster machining and higher productivity, the effective volume of material that can be removed within the useful life of the tool is reduced. Hence an optimal cutting speed has to be evolved, considering factors like the volume of material removed, tool cost and tool change cost / time.
3.6 ANALYSIS OF TOOL VIBRATION

Under ideal conditions, the surface roughness profile is formed by the replication of the tool tip profile at regular intervals of feed per revolution. However, many other factors like the dynamics of the metal cutting operation, elastic recovery of the cut region of the work material, ploughing, spindle rotational error and tool vibration, leading to the relative displacement of the tool and work material contribute to the modification of surface profile. In hard turning, theoretically tool vibration is likely to play a significant role in surface generation. Also, tool vibration is significantly influenced by tool wear. Hence an attempt was made to monitor the tool vibration, to obtain the information about the tool wear status.

The spectrum analysis such as the Fast Fourier Transform (FFT) and the wavelet transform are widely used to study the time series data. Hence to gain better understanding the tool wear causing the surface roughness generation, the spectrum analysis of vibration signals were carried out.

Assuming the vibration signals to be stationary, the FFT was performed on the vibration signals to extract information about the various frequency components of the vibration signal. The FFT enables to extract the features in waveform of a signal by transforming the time domain data into the frequency domain data.
Figure 3.9 Typical Vibration Signal (Cutting Speed Direction)

Figure 3.10 Typical FFT Plot of Vibration Signal (Cutting Speed Direction)
Figure 3.9 shows a typical time series data of the captured vibration signal, from vibration sensors mounted on the tool shank. A computer program was written to perform the FFT and the output of the program showing the various frequency components is shown in figure 3.10. The FFT plots of the vibration signal measured at various stages of flank wear is shown in Figure 3.11.

![Figure 3.11](image)

**Figure 3.11 Power Spectrum Plots at Various Flank Wear States (Cutting Speed 100 m/min)**

Attempts were made to correlate the vibration signal measured in the main cutting speed direction and the feed direction and the tool wear. Various metrics, like the RMS value of the vibration signal, mean vibration, power of the vibration signal calculated from the FFT plots, and the power measured at various frequency bands, were all calculated and plotted against tool wear. But no positive correlation could be established between these parameters and tool wear.

Similarly, the vibration signal was decomposed, using bi-orthogonal wavelets. A five level decomposition was resorted to. The statistical
parameters of the wavelets were plotted against the tool wear. But again, there was no positive correlation.

3.7 MAJOR CONCLUSIONS OF THE PRELIMINARY EXPERIMENTS

Tool wear studies were conducted, using CBN inserts at three different cutting speeds. The results of the experimental work are summarized as follows.

- The conventional three phases of tool wear, namely the initial run-in wear, steady state wear and rapid tool wear are not clearly distinguishable.

- Flank wear land, the parameter governing the tool life increases rapidly as the cutting speed was increased. Tool life at the cutting speed of 70 m/min was approximately 4 times that of tool life at 130 m/min, for a feed of 0.05 mm/rev and depth of cut of 0.1 mm. This makes the suitable trade off between higher productivity and higher tool life necessary.

- The flank wear of the cutting tool also significantly affects the surface roughness of the workpiece. There is a marked degradation of the surface roughness, as the flank wear land of the tool crossed the critical value of 0.3 mm.

- When the flank wear land remains within 0.3 mm, the surface roughness (Ra) value remains well within 0.7 μm making the process comparable to the grinding operation.
While studying the level influence of the cutting speed on the life of CBN tools, it was observed that the cutting speed has a relatively low influence on tool life, when compared to high speed steel and carbide cutting tools.

An unsuccessful attempt was made to monitor the hard turning process using vibration sensing. Though various signal process techniques, including the analysis of signal at various frequency domains and the wavelet analysis of vibration signal were used, extracting the signal metrics pertaining to tool wear was not possible. Probably this could be, because of the high rigidity of tool holding system and very low signal-to-noise ratio.

3.8 CHAPTER SUMMARY

This chapter dealt with the results of certain preliminary experimental works carried out to monitor the hard turning process using vibration signals. The tool wear curves were obtained and surface roughness was found to be significantly influenced by tool wear. But attempts to monitor the tool wear using vibration signal were unsuccessful.