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TOOL WEAR MONITORING IN TURNING PROCESS USING VIBRATION MEASUREMENT

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Abstract

The main objective of this paper is to develop a signal processing technique using vibratory signals in order to provide a robust monitoring system for early detection of tool wear in turning, thus increasing machining performance. The method is based on the changes in the vibration signatures that can be captured during the turning operation all along the tool life. Several signal processing techniques based on time and frequency domain analysis are proposed in order to extract a large number of indicators of cutting tool state. We also show a significant correlation between the tool flank wear and the statistical parameters. The tool life is established as a function of the acceleration amplitude of acquired vibrations. These results provide preliminary elements towards the implementation of an on-line monitoring strategy.

INTRODUCTION

Machining operations such as turning and milling are basically used in industrial manufacturing processes to achieve the machined workpiece under specified characteristics (geometry, surface roughness, etc). This process is based on removing of matter by means of a cutting tool. The latter continuously holds contact with the workpiece and the chip over a very small area of a few square mm where high temperature and pressure occur. The consequence is unavoidable and progressive cutting tool wear [1].

In these conditions, tool wear is caused by abrasion, erosion, diffusion or other mechanisms and cutting tool wear appears in several forms: flank wear, crater wear, chipping, etc. These forms essentially depend on cutting tool characteristics, workpiece material, cutting conditions and machining types [8]. This phenomenon decreases the quality of machining because of loss in surface integrity, chatter amplification and possibly workpiece damaging.

Finally, tool wear results in some degradation of the dimensional accuracy and surface quality of the finished product [2]. For these reasons, it is necessary to develop a monitoring system for early detection and evaluation of the tool wear during the cutting process.

From the view point of monitoring, the most important wear parameters are the width of flank wear (consequence of workpiece friction on the clearance face of the cutting tool) and the depth of crater wear (formed on the rake face of the cutting tool by chip friction) [8].

Various methods have been investigated for tool wear monitoring. Globally, these methods can be classified into direct and indirect approaches. The direct methods measure the flank and the crater wear of the cutting tool, generally using optical methods such as a white light interferometry [2] and CCD camera [9]. However, these techniques are unable to assure a continuous monitoring of cutting tool state. Hence, indirect techniques have been proposed to perform monitoring.

The indirect methods involve the measurement of various parameters which can be correlated with the cutting tool state. Let us quote for example acoustic emission [4], cutting force [3] and vibration [6]. Among them, as was shown in a ref. [5], a number of studies have found that the vibration analysis is an efficient solution for tool wear monitoring [1, 7].

In this paper, we propose to study the tool state during machining by using vibration measurements. In the first part we described the experimental setup, machining conditions and data acquisition. The second part showes the results obtained from the time and frequency domain analysis.
The evolutions of frequency and statistical parameters according to tool wear levels are studied in order to evaluate a possible utilisation of each parameter as wear indicator.

EXPERIMENTAL SET-UP AND DATA ACQUISITION

Cutting experiments are driven using a computer numerically controlled lathe (CNC): Conventional plus T400 (figure 1.a). The speed of spindle rotation lies in the 100-4000 rpm range and the feed rate in a 0.1 to 8 m/min interval.

The workpiece material is a slightly alloyed steel (A37) and the cutting tool is a SN MG TP 200 (120408-MF2) with a coated WC insert.

In this study, a Brüel&Kjaer 4507 device has been used, together with unidirectional piezoelectric accelerometers whose characteristics are: mass: 4.8g size: 10 mm^3 and sensitivity: 10 mV/ms^{-2}.

A monitoring strategy has been devised using three accelerometers fixed on the tool holder in the three directions X, Y, Z (see figure 1.b). Using three accelerometers allows to record as much vibration data as possible from the cutting process. This procedure is likely to generate a large number of indicators which may be helpful to acquire maximum information about the wear state of the tool.

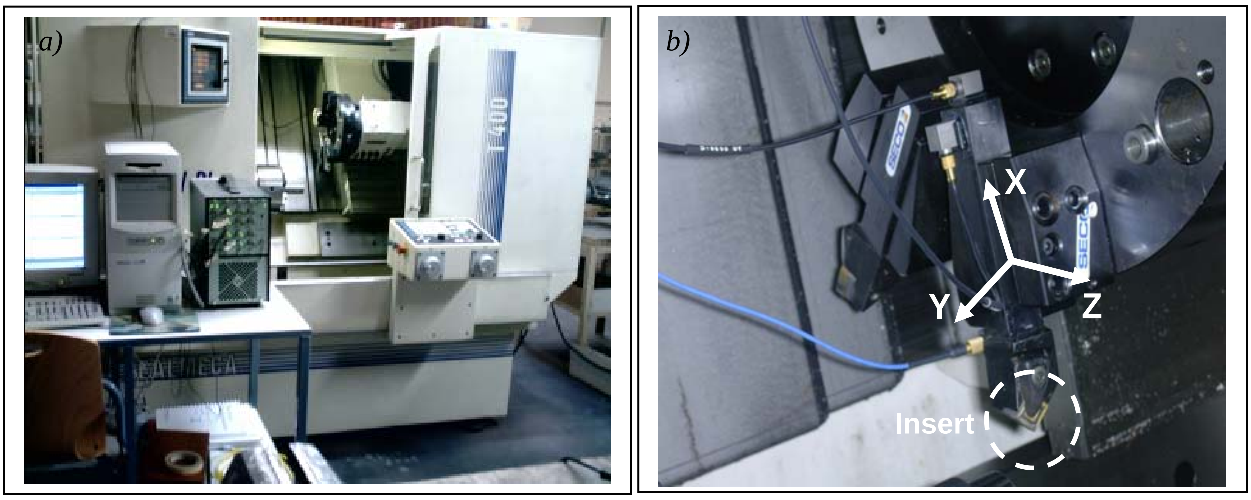

Figure 1 – a) CNC Lathe and acquisition system, b) sensors on the tool holder

Cutting operations, conducted under dry conditions, are performed in the following cutting conditions: cutting speed = 405 m/min, feed = 0.2 mm/tr and depth of cut = 1mm.

The sensor signals are captured during 4 s observation time and transmitted through three channels, then sampled at 8 kHz rate. Collected data is directly stored on the PC hard drive (figure 1.a) by means of the Pulse Lab Shop® software developed by Brüel&Kjaer. Signal processing was performed within Matlab environment.

Figure 2.a shows result from one observation (one pass) of a 4 second signal, corresponding to a sensor fixed on the cutting tool holder along the X direction. In this figure we can observe the contact of the tool with the material at point A, the cutting part is from point A to point B and the exit of the tool from the matter is at point B. Furthermore, the cutting part is segmented into 3 zones: attack zone (1), stable cutting (2) and quit zone (3).

The vibration response is a zero mean normal distributed signal as shown in the calculated histogram in figure 2.b.

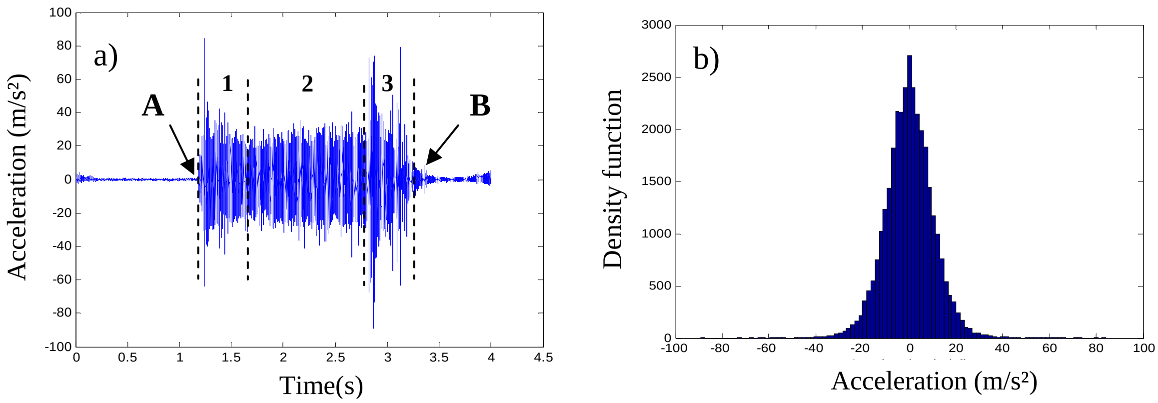

Figure 2 - a) A typical 4s time signal from a cutting process, b) histogram of the cutting signal

As a complement to the vibratory approach, a binocular microscope (figure 3) is used to measure after each test the width of the wear developed on the major flank of the cutting tool.

Figure 3 – Binocular microscope

RESULTATS AND DISCUSSION

Under the previously described cutting conditions, 51 observations are required (from the first use up to destruction). This number of tests is sufficient to generate tool damage.

First, the study of vibratory evolution with respect to the tool wear has been carried out and the results are shown in figure 4.

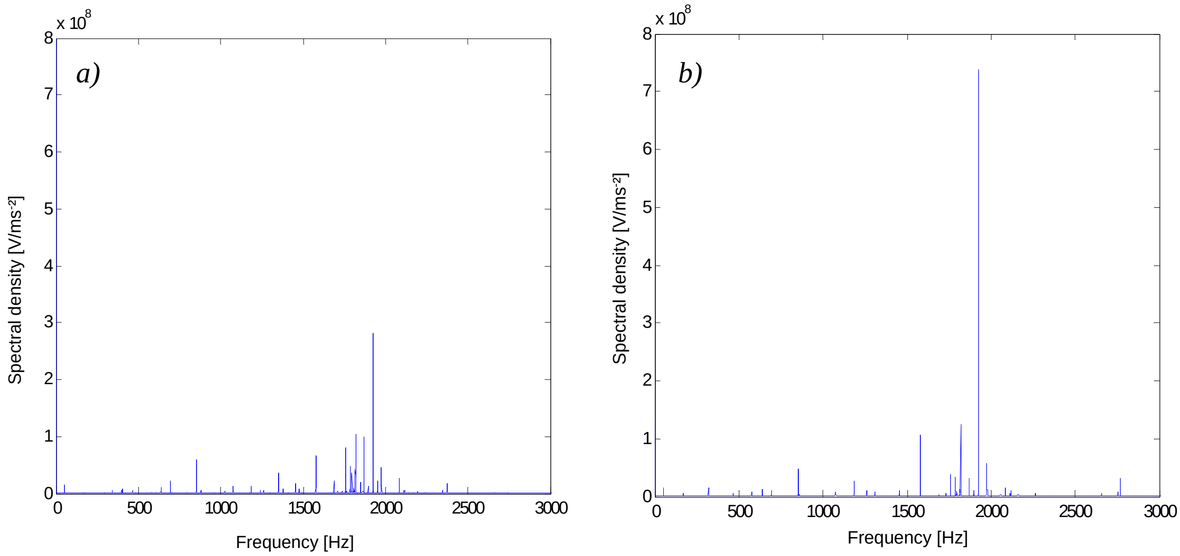

Figure 4 – a) Spectrum of new insert, b) spectrum of worn insert

In the case of a new tool (figure4.a), the peak at 2000 Hz has a magnitude almost three times smaller than the magnitude of the same frequency in the case of a worn tool (figure4.b). Taking that into account and from mechanical considerations it results that the 2000 Hz frequency is an eigenfrequency of the cutting tool.

Next, time domain analysis is performed on the stable part of the cutting signal (zone 2 in figure 2-a), by calculating the signal variance (which expresses the distribution variability compared to the averaged value), its entropy (which measure the disorganization degrees of the distribution), the kurtosis (which provides an evaluation of the distribution flatness, compared to that of a normal distribution) and the skewness (which characterizes the distribution asymmetry). This information from the three direction accelerometers (X, Y, Z) is recorded as a series of functions of the observation number, which is equivalent to cutting advancement.

Figures 5, 6, 7 and 8 respectively present the variance, entropy, kurtosis and skewness profiles acquired from the Z direction. Similar profiles are obtained from the other directions.

The variance is large for the 8 first observations; which can be explained by the breaking-in time of the insert (first use). Furthermore after this delay the insert displays a smooth behaviour and the variance stabilises at a low level. After the 28th observation the variance abruptly changes and once again becomes erratic at a higher level. This behaviour is due to the increase of friction and cutting forces when the tool became worn.

On the other hand, the entropy reaches high absolute values (maximum = 4.10^8) during breaking-in time - the eight first observation – because of large dispersion of the signal. During the following observations 9 to 29, the entropy falls down to close to zero values with smooth variations. At that time, the machining process is stable and the acquired signal distribution presents low dispersion. However, after measurement 29, the entropy suddenly increases with a somewhat erratic profile. This can be explained by an excessive tool wear. Hence, the entropy calculation confirmes, as was found from variance, that tool damaging appeared at the 29th test.

From these observations it results that vibration analysis can be used to evaluate the tool state progression and to provide reliable information about the cutting tool wear.

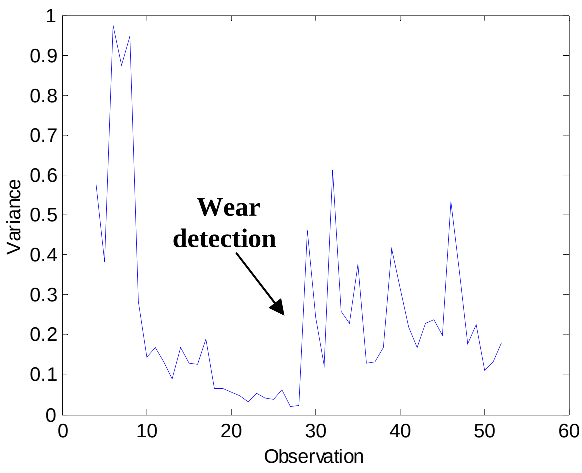

Figure 5 – Variance versus observation

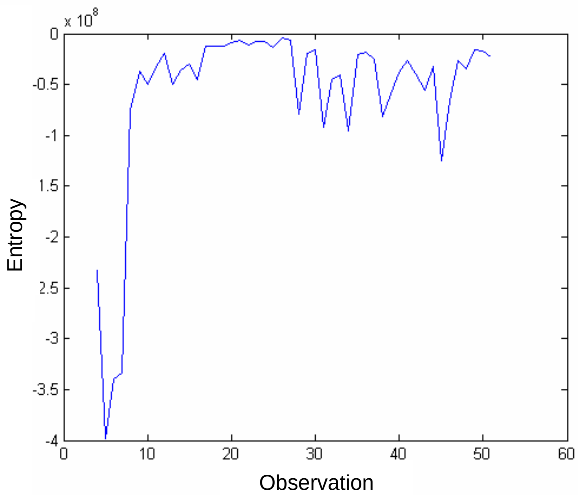

Figure 6 – Entropy versus observation

The Kurtosis and the skewness profiles show that generally all tests have a normal distribution, except a noticeable wear detection at the 29th observation.

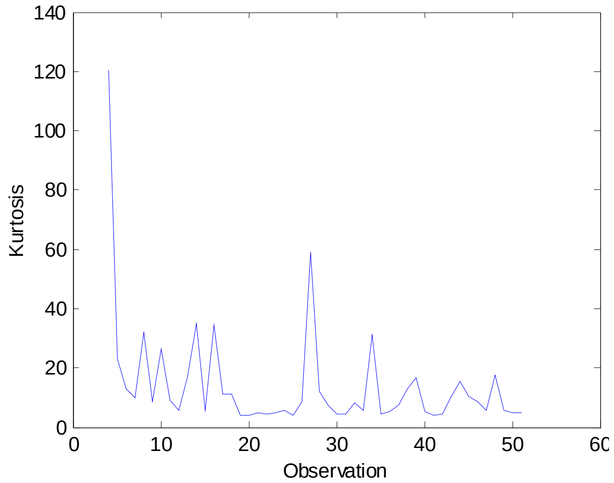

Figure 7 – Kurtosis versus observation

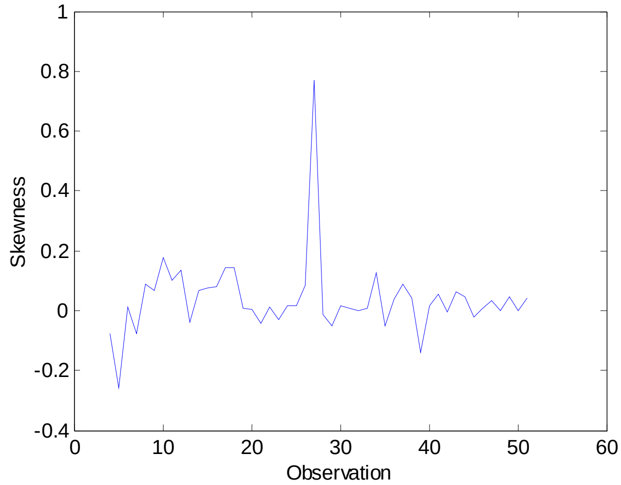

Figure 8 – Skewness versus observation

Furthermore, the tool wear width is calculated all along the cutting progression from the images given by optical microscopy as shown on Figure 9.

Figure 9.a, presents the clearance face of the new cutting tool. Figure 9.b shows a measurement of flank wear detected after the 28th observation. At that time the width of flank wear is 0.14 mm. Figure 9.c shows the aspect of this flank wear at the last experiment. This flank wear is 0.20 mm wide. In this experiment no crater wear was observed.

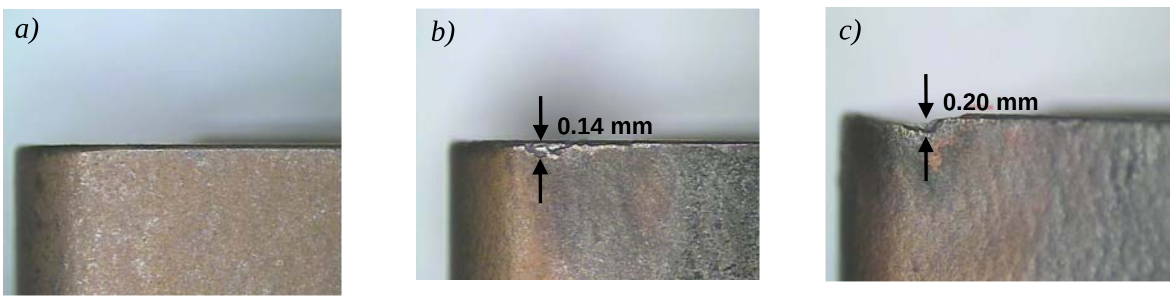

Figure 9 – a) New insert, b) flank wear at 29th test, c) flank wear at the last test (51th)

In this work we have shown how vibration analysis can provide an efficient method for tool wear detection and cutting tool monitoring. Basically this technique performs calculation of various vibrationnal parameters, which in the present case have all indicated the tool wear presence after the 28th cutting test. The same conclusion is also obtained and confirmed by analysing the images captured by means of binocular microscope.

CONCLUSION

The present study investigates the use of vibration measurement to perform the on-line tool-failure detection and monitoring of coated tool in turning.

This work confirms that vibratory analysis can provide an efficient technique for detection and monitoring of cutting tool wear. Moreover, it was shown that during the turning process the state of the cutting tool, as observed in the microscope, is closely related with some parameters obtained from vibratory signal processing. However, in this preliminary work we only used one type of machining (turning) at constant cutting conditions and one type of material (steel).

Future work will include a range of different tools and materials to confirm these findings.

Ultimately, the aim of this analysis through several parameters: variance, skewness, kurtosis, entropy function and flank wear measurement, is to implement a neural technique as a strategy for automatic tool wear monitoring.

REFERENCES

[1] S.Braun, E.Lenz, “Machine-tool wear monitoring”, in Mechanical Signature Analysis, Academic Press, London, GB, (1986) 321-342.

[2] A.Devillez, S.Lesko, W. Mozer, “Cutting tool crater wear measurement with white light interferometry”, WEAR **256** (2004) 56-65.

[3] E. Kuljanic, M. Sortino, “TWEM, a method based on cutting forces monitoring tool wear in face milling”, Machine Tools & Manufacture **45** (2005)29-34.

[4] X.Li, “A brief review: acoustic emission method for tool wear monitoring during turning”, Machine Tools & Manufacture **42** (2002)157-165.

[5] G.H. Lim, “Tool-wear monitoring in machine turning”, Journal of Materials ProcessingTtechnology **51** (1995)25-36.

[6] A. OUAHABI, W. RMILI, R. SERRA, C. GONTIER, R.Leroy “Vibratory analysis for tool wear monitoring during machining (Turning, Milling)”, 5th International Conference Acoustical and Vibratory Surveillance Methods and Diagnostic Techniques, Senlis, France, Octobre 2004.

[7] C. Scheffer, P.S. Heyns, “Wear monitoring in turning operations using vibration and strain measurements”, Mechanical Systems and Signal Processing **15(6)** (2001) 1185-1202.

[8] B.Sick, “Online and indirect tool wear monitoring in turning with artificial neural networks: a review of more than a decade of research”, Mechanical Systems and Signal Processing **16** (2002) 487-546.

[9] K.C.Tsao, A.B.Husein, S.M.WU, “Cutting tool crater wear measurement by the lapping-comparator technique”, Machine Tool Design and Research **8** (1968) 15-26.