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Evaluation Tool Condition of Milling Wood on the Basis of Vibration Signal

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Abstract. The paper presents preliminary results of the research of tool condition monitoring based on both original and demodulated signals measurements of an vibration generated by a cutting process in milling. The experiments have been performed on the milling center (CNC). Because the dynamic characteristics of tool vibration in machining process will change with tool wear development, which is one of the important dynamic characteristics of tool vibration. The signals were analyzed through FFT analyzer and computer (realised in the environment of NI LabVIEW). Work supported by the Grant 3 P06L 025 24 from Committee of Scientific Research of Poland.

1. Introduction

The need to maintain high product quality while improving production rates has driven the wood products industry to automate many machining operations. Increases in labor and raw material costs have also provided the incentive to increase production throughput as well as reduce the number and technical skill levels of the required workforce. A disadvantage of this trend is that a change in the condition of the machining process or the resultant quality of the workpiece can go undetected for a substantial period of time causing significant impact on the economics of the machining operation.

In order to operate a fully automated machining system without trouble, an effective monitoring system for the machining states is required. For any machining system, one of the most important kinds of information in the machining process is tool failure, such as tool wear or tool breakage. The progressing state of tool wear in the machining process is very useful information for the determination of the following cutting conditions. Although many methods for in-process monitoring of the tool wear states were proposed and tried, most of them are of passive type. In the methods, the signals from the machining points or fields, such as vibration, sound, AE, cutting force, temperature and etc., are passively detected as sets of the time series data, and their changing characteristics with tool wear development will be compared with those of the wear-free tool to monitor the tool wear states. The relations between the tool wear development and the characteristic parameters obtained from time series data must be prepared preliminarily in different cutting conditions. Evidently, these problematic situations would make the methods difficult and uncertain for a reliable and practical monitoring system.

2. Vibration in the cutting process

The machining industry has an increasing need for improved characterization of cutting tools and for controlling vibration and chatter during the milling process. If uncontrolled, vibrations and chatter can reduce surface finish, limit dimensional accuracy, increase tool wear, create high levels of noise and can even be the cause for tool breakage. These undesirable performance attributes can, in turn, lead to increased machine wear, reduced throughput and higher scrap production. Furthermore, there is a growing demand for high-speed milling, for the use of small size tools and for machining difficult advanced materials. Conventional approaches for control of vibrations and chatter, such as increasing the stiffness of the tool and reducing the cutting depth or machine speed, are no longer satisfactory and clearly reduce production throughput.

3. Fast Fourier Transform (FFT)

An energy-limited signal $f(t)$ can be decomposed by its Fourier transform $F(\omega)$, namely

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(\omega) e^{j\omega t} d\omega \quad (1)$$

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt \quad (2)$$

$f(t)$ and $F(\omega)$ are known as a pair of Fourier transforms. Equation (2) implies that $f(t)$ signal can be decomposed into a family with harmonics $e^{j\omega t}$ and the weighting coefficient $F(\omega)$ represent the amplitudes of the harmonics in $f(t)$. $F(\omega)$ is independent of time, it represents the frequency composition of a random process, which is assumed to be stationary so that its statistics do not change with time. Fourier transform has been successfully used to process the AE signal during turning. In [1], experimental results have shown that the magnitude of the AE in the frequency domain was sensitive to the change of tool state. However, the vibration signal is essentially non-stationary. If we calculate the frequency composition of nonstationary signals by using Fourier transform, the results are the frequency composition averaged over the duration of the signal. As a result, Fourier transform cannot describe adequately the characteristics of the transient signal in the lower frequency.

4. Experimental test setup

The experiments have been performed on the milling center Busellato JET 130. In experiments was used based-wood materials-laminated chipboard. Dimensions of the specimens which were prepared for the machining were as follows: 2700x30x18mm (Figure 1).

The cutting tools was a DIMAR HW $\phi 12 \times 51$. In research applications four cutting tools. The feed speed were constant. The spindle speed was different (Table 1). The signals were digitized and stored into a computer using a Computer Boards NI PCI-6111 analog-to-digital converter. The sensor used included: Kistler 8141A121. VB_B was selected as the tool wear measure. The original (V_{raw}) and root mean square (V_{RMS}) signals were recorded on a hard disk PC in a digital form. In the course of breaks executable measurements VB_B with the of workshop microscope.

As raw vibration signal (V_{raw}) has a high frequency, its recording and analysis in the original form is expensive. Therefore, usually root mean square value (V_{RMS}) or some other form of demodulation is applied. Signals rectified in this way have much lower frequency, so they are much easier to handle, being in most cases still useful enough. However, that kind of signal processing should be carried out with care, especially as far as integration time constant is concerned. Furthermore, if the raw signal has been deformed, this deformation can be completely concealed by demodulation and leads to deceptive conclusions. Some aspects of vibration signal demodulation will be discussed here as well.

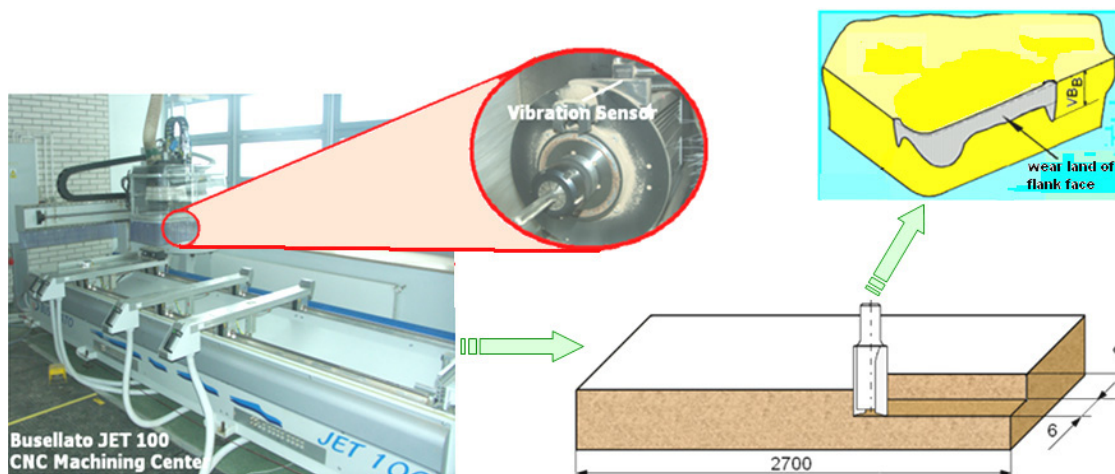


Figure 1. CNC Machining Center and measurement VB_B .

The first step in evaluating vibration as a monitoring technique was to determine the appropriate mounting location for the sensor. Previous work has shown that mounting the sensor on a stationary tool is best.

Table 1. Cutting parameters.

Tools	Feed (m/min)	Spindle speed (rpm)
1	8	18000
2	8	14000
3	8	10000
4	8	60000

Previous work for sawing and milling, that mounting the sensor on the spindle housing. The vibration sensor was placed on the spindle housing (Figure 1).

Time history data were collected for this sensor at a rate of 50.000 samples per second. The sensor had an upper frequency range of 10kHz.

5. Results

In research individual tool cutting perform about 1km cutting distance. Figure 2 shows results of high-pass 10Hz and low-pass 100kHz filtering of the original signal and RMS from cutting in the single operation for new end wear tools. The standard integration time constant of the RMS converter is 1.2 ms, but 0.12, 12 and 120ms are also available. In the experiments was used 1.2ms converter.

Figure 2 shows some examples of tool vibration waveforms in the cutting time. The increase rate of the vibration amplitude depends on the flank wear. When the flank wear is equal to or over 0.25mm, the increase rate becomes more, as shown in Figure 3. The reason for the phenomenon may be that an additional vibration of the tool vibration system was excited by the friction between the finished surface and the flank worn land. In the frequency domain, the phenomenon can be clearly explained. Figure 4 shows the sample of power spectrum characteristic of the tool vibration in the cutting direction when the flank wear values are equal to 0.0 and 0.25 mm.

From Figure 4, the characteristics of increment of the tool vibration energy and the shift of the peak frequency from 400 to 1200Hz with tool wear development can be clearly seen. The shifting characteristics of the spectrum peak frequency with tool wear development were also reported in some study papers [2,3]. The result is also consistent with the basic theory on the mutual relation between the spindle speed ratio and the vibration frequency.

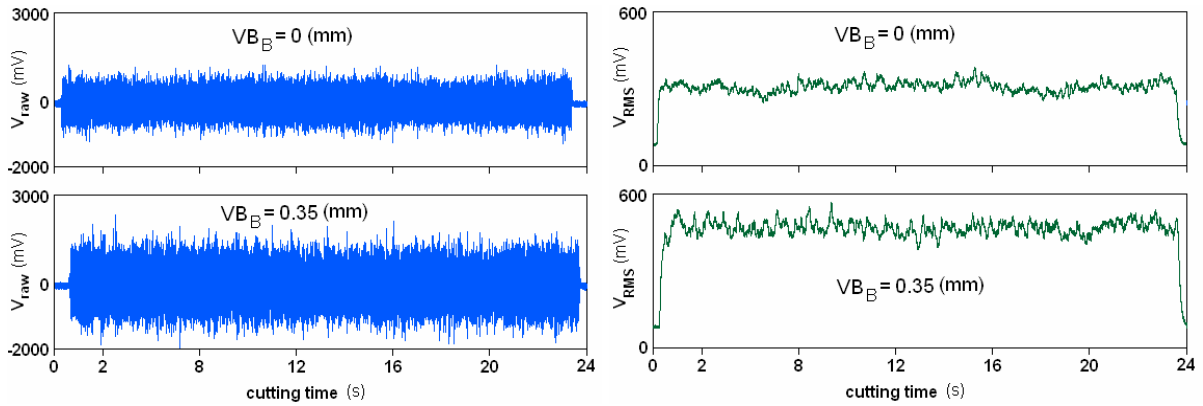


Figure 2. Representative examples of vibration signal generated in milling: V_{raw} and V_{RMS} for 18000rpm.

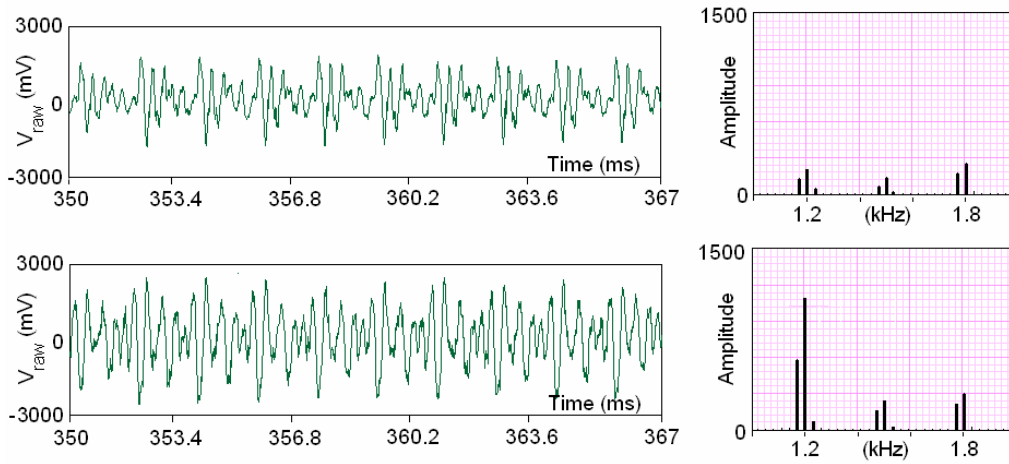


Figure 3. Representative examples of vibration signal generated for 18000rpm and FFT.

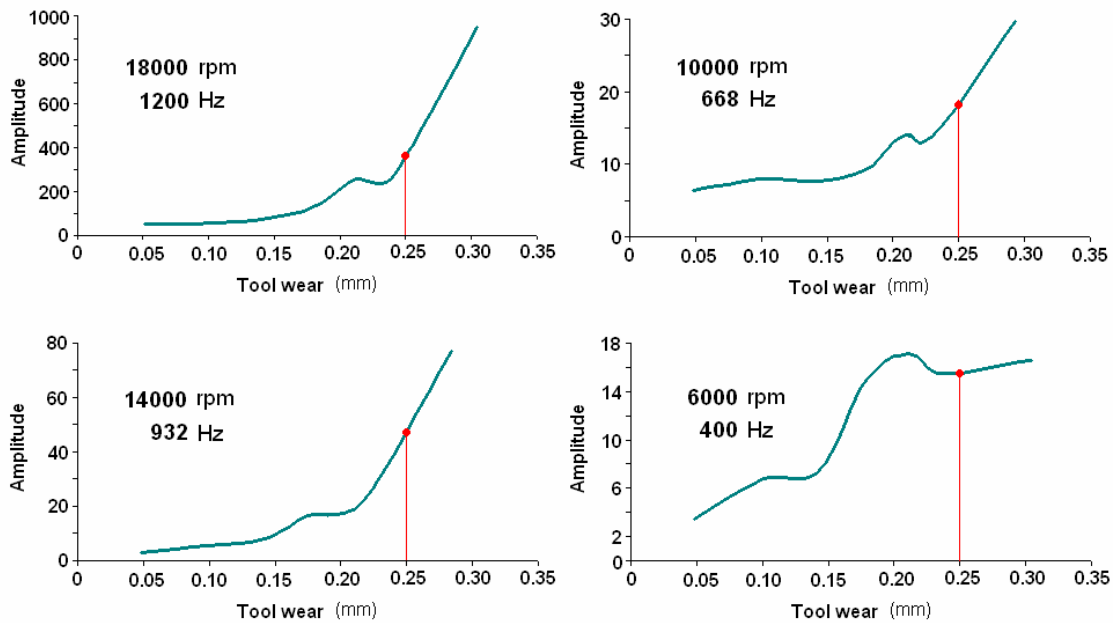


Figure 4. Amplitude vibration (V_{raw}) signals with tool wear.

Figure 4 presents the average value FFT of the vibration signal obtained in three selected tool lives. It can be seen that this signal feature is monotonic function of the used up portion of the tool life (tool wear). Tool wear estimation is based on reverse function, where the value of the signal feature determines the tool wear estimation. As the monotonic functions are reversible, all TCM systems using such strategies must fail if the signal feature appears to be non-monotonic.

The assumption about monotonic, increasing character of signal feature (FFT) dependence on the tool wear, being the foundation of most TCM strategies, excludes many useful features. Such transformation also makes it easy to use the signal features which are non-linear, decreasing or negative.

6. Conclusion

The objective of this project was to investigate the feasibility of using process-monitoring techniques that have demonstrated at least limited success in monitoring wood cutting. A series of sensing techniques was investigated under the same cuffing conditions on a CNC router.

Monitoring spindle vibration using an accelerometer appeared to be the best approach. This susceptibility to "background noise" could make this sensor approach unacceptable for industrial environments even though the literature includes articles on laboratory success with the sensor in a process-control study of the CNC router. For process-monitoring applications, this relationship between the accelerometer output and tool wear should be adequate for a CNC router. The operator could establish where on the spindle vibration/tool wear curve the quality of the product decreased below an acceptable level, thereby indicating a tool change was needed. The signal from the accelerometer would then be monitored. If a potentially unacceptable condition arose as indicated by the sensor output, an operator would be notified who would then verify the machining condition and take the appropriate action.

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