VIBRO-ACOUSTIC SIGNALS AS A SOURCE OF INFORMATION ABOUT TOOL WEAR DURING LAMINATED CHIPBOARD MILLING

JACEK WILKOWSKI, JAROSŁAW GÓRSKI
WARSAW UNIVERSITY OF LIFE SCIENCES – SGGW, FACULTY OF WOOD TECHNOLOGY
WOOD MECHANICAL PROCESSING DEPARTMENT
WARSAW, POLAND

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ABSTRACT

The basic aim of the study is to assess, on an experimental basis, the potential usefulness of vibro-acoustic signals (mechanical vibration, noise and acoustic emission) for the indirect assessment of geometrical and technological tool wear indicators during the laminated chipboard milling. The most useful, from tool condition monitoring point of view, was vibration signal (measured by means of accelerometer attached to fast headstock of CNC machine tool). The most telling feature of vibration signal was the amplitude visible in the power spectrum of this signal for the narrow frequency range, which was connected with the tool blades passage frequency (600 Hz).

KEYWORDS: Tool wear monitoring, vibrations, acoustic emission, noise.

INTRODUCTION

Tool wear is one of the most important (from scientific and practical point of view) problems in wood machining. It is a well known fact, that the most effective and accurate woodcutting process requires really sharp (unused) tool. The significant progress in tool wear inevitably leads to the poor quality of machining. During laminated chipboard machining a worn-out tool causes characteristic damages (chipping) of laminate, which can be observed along the machined edge of a workpiece. Therefore the quantitative indicators of the damages of laminate can be used as so-called technological indicators of tool wear. The standard group of such indicators contains: a number of laminate chips (Boehme and Munz 1987, Lemaster et al. 2000) and the width (Porankiewicz 1993, Pałubicki 2006) or the surface area (Kowaluk 2005, Górski and Wilkowski 2006, Pałubicki 2006) of the delaminated zone. Nevertheless the most objective way of tool wear assessment is geometrical indicators measuring (Jemielniak 2002) An effective geometrical indicator of tool wear may be any, explicitly defined and measurable, change in tool’s geometry, which is a natural result of machining process. A clear example of such indicators is width of wear land observed in
flank face (Salje et al. 1985, Szwajka and Górski 2006, Wilkowski and Górski 2006) or in rake face (Stuhmeier 1989). Unfortunately, the measuring of tool wear's geometrical indicators usually demands a break in machining process which is troublesome in industrial practice.

During the standard short-run production the progress of tool wear is usually assessed by the machine tool operator who subjectively (according to his own professional experience) monitors and analyzes appearance of machined surface, shape of chips, noise generated during cutting etc. On the basis of this information the man decides when to exchange the worn-out (unfit to continue working) tool. During the mass production, when human supervision of machine tool is not continuous but rather limited in time, a tool is recognized as worn-out (unfit to continue working) after some fixed period of time or distance of cutting. It is quite simple but not a perfect solution because, in spite of invariability of cutting conditions, the real tool life is always, in practice, a random variable. When the cutting process takes place by the means of completely automated, flex machine tool (or flex machining system) a special, automatic Tool Condition Monitoring (TCM) system should be used. TCM system is based on indirect tool wear monitoring but (contrary to the subjective tool wear assessment made by the machine tool operator) demands special sensors of vibration, noise, acoustic emission, force etc. and objective, computer strategy of tool wear identification (Jemielniak 2002).

The application of a reliable TCM system is a necessary condition for the safe and long-term (at least 8 hours) work of the flex wood machining system without the continuous presence of the machine tool operator (Górski 2002). There is an enormous gap between the low level of the basic knowledge about TCM and high level of the timber industry's need for a really effective TCM. High and constantly growing level of this need results from the dynamic development and popularization of full automated wood machining systems.

The general structure of the standard TCM system is based on the fact that various physics quantities can be useful, indirect source of information about tool wear. Appropriate sensors convert chosen physics quantities into electric signals. These can be processed by the means of analogue filtering, analog-digital conversion, collected and analyzed (by means of RMS or standard deviation calculation as well as by means of FFT or STFT) to extract proper information and to identify state of tool (Jemielniak 2002).

The primary aim of the study is to assess, on an experimental basis, the potential usefulness of vibro-acoustic signals for the indirect assessment of tool wear's geometrical and technological indicators during the laminated chipboard milling.

**MATERIAL AND METHODS**

The experiments were realized by the means of a standard machining center (BUSELLATO JET 130) and a standard double-bit milling cutters (DIMAR HM DynamicTM line, diameter: 12 mm, length of the working part: 51 mm). Work material was a standard laminated chipboard (Kronopol 511 SM). The experimental set-up (Fig. 1) contained:

- acoustic emission measuring system (contact sensor - Kistler 8152B, amplifier Kistler - 5125B),
- mechanical vibration measuring system (accelerometer - Kistler 8141A, amplifier - Kistler 5127B),
- noise (sound pressure) measuring system (microphone and preamplifier - B&K 4189, amplifier - B&K NEXUS 2690),
- two connection boxes (NI BNC-2110),
- two data acquisition cards (NI PCI-6111, NI PCI-6034E).
The experiment required the use of two different data acquisition cards because two different sampling frequencies were needed (2 MHz for acoustic emission signal and 50 kHz for vibration and noise signal).

Fig. 1: The scheme of experimental set-up

The localization of sensors is shown in Fig. 2. The accelerometer was fixed to the fast headstock of machine tool. The contact sensor of AE was located directly on the workpiece. The distance between a microphone and the cutting zone was about 300 mm (Fig. 2). The scheme of machining operation is shown in Fig. 3. Cutting parameters were as follows: feed speed – 12 m.min\(^{-1}\), spindle speed – 18000 rpm. In the experiment the total cutting distance covered by each milling cutter was over 5 km.

Geometrical and technological tool wear indicators were observed during experiments. The geometrical indicator – maximum width of wear land observed in flank face (VB\(_{\text{max}}\) (mm)) – was measured by the means of a laboratory microscope (Fig. 4). The technological indicator – surface area of the delaminated zone (S (mm\(^2\).m\(^{-1}\))) – was determined by the means of digital photographs processing. The problem of delaminating (chipping of laminate) after milling is shown in Fig. 5. The surface area of delaminated zone was calculated separately for conventional cutting and for climb cutting.

Fig. 2: The scheme of sensors localization

Fig. 3: The scheme of machining operation
Acoustic emission (AE), vibration (V) and noise (N) signals were processed and analyzed by the means of special software developed in NI LabVIEW environment. Time-domain and frequency domain analysis was realized. A lot of standard, statistic features (RMS, standard deviation, kurtosis etc.) of all the recorded signals were calculated. Frequency-domain analysis was realized by the means of FFT (Fast Fourier Transform) and STFT (Short-Time Fourier Transform) (Fig. 6).

RESULTS AND DISCUSSION

All the recorded signals (acoustic emission, vibration and noise) were analyzed in order to find the signal which was the most correlated with the geometrical ($V_B^{max}$ (mm) - maximum width of wear land observed in flank face) and technological ($S$ (mm$^2$.m$^{-1}$) - surface area of delaminated zone) tool wear indicators. It turned out that the strongest correlations was observed for mechanical vibration signal. The most telling feature of vibration signal was the amplitude visible in power spectrum of this signal for the narrow frequency range, which was connected with the tool blades.
passage frequency (600 Hz). The tool blades passage frequency was calculated according to the following formula:

\[ f_p = \frac{n \cdot z}{60} = 600 \text{ Hz} \]

where:
- \( f_p \) (Hz) - tool blades passage frequency (\( f_p = 600 \text{ Hz} \)),
- \( n \) (rpm) - rotation speed of spindle (\( n = 18000 \text{ rpm} \)),
- \( z \) - number of blades (\( z = 2 \)).

The relationship between the increase in vibration signal amplitude (\( V_{600 \text{ Hz}} \)) and geometrical tool wear indicator (\( V_{\text{Bmax}} \)) is shown in Fig. 7 (separately for four different milling cutters) and in Fig. 8 (for all tools together). The most important, from practical point of view, is significant correlation observed for all tools together (\( R^2 = 0.79 \)).

The relationship between increase in vibration signal amplitude (\( V_{600 \text{ Hz}} \)) and technological tool wear indicator (\( S \)) is shown in Fig. 11 (separately for four different milling cutters) and in Fig. 12 (for all tools together). The data mentioned above (especially relatively low level of correlation for all tools together - \( R^2 = 0.56 \)) suggest that vibration signal is not really effective source of information about technological aspect of tool wear problem.

Unfortunately, the features of vibration signal which were determined during time-domain analysis (RMS) proved to be absolutely worthless from tool wear monitoring point of view (Figs. 9, 10). In contrast to vibration signal no really significant difference was observed between the usefulness of RMS of noise signal (\( NRMS \)) and the amplitude visible in power spectrum of noise signal for the narrow frequency range, which was connected with the tool blades passage frequency (\( N_{600 \text{ Hz}} \)) (Fig. 13 ÷ Fig. 16). Nevertheless, the diagnostic usefulness of noise (acoustic pressure) signal turned out to be distinctly lower than the usefulness of vibration signal. It is true that correlation between, for example, RMS of noise signal and geometrical indicator of tool wear, observed for a particular tool, was statistically significant and quite useful (Fig. 15 – \( R^2 = 0.85 \div 0.91 \)) but the basic problem of noise signal was the low repeatability of experiment results for different tools. Hence the analogous correlation observed for all the tools together was rather poor (\( R^2 = 0.61 \)). One of the most probable reasons of this problem was external noise generated by other machines.

Noise signal as well as vibration signal turned out to be evidently worse source of information about technological than geometrical indicator of tool wear (Figs. 17, 18).

Acoustic emission signal, measured by a contact sensor attached to the workpiece, turned out to be absolutely useless as a source of information about any aspect of tool wear problem. There was no, statistically significant, correlation between any features of acoustic emission signal and geometrical or technological indicators of tool wear.

The influence of the type of cutting (normal versus climb cutting) on technological indicator of tool wear is shown in Fig. 19. In spite of tool wear’s level the conventional cutting gave better quality (less damage of laminate) than the climb cutting.
Fig. 7: The relationship between the increase in vibration signal amplitude (V600 Hz) and the geometrical tool wear indicator (VBmax)

Fig. 8: The relationship between the increase in the vibration signal amplitude (V600 Hz) and the geometrical tool wear indicator (VBmax) for all the tools together

Fig. 9: The relationship between the increase in RMS of vibration signal (VRMS) and the geometrical tool wear indicator (VBmax)

Fig. 10: The relationship between the increase in RMS of vibration signal (VRMS) and the geometrical tool wear indicator (VBmax) for all the tools together

Fig. 11: The relationship between the increase in the vibration signal amplitude (V600 Hz) and the technological tool wear indicator (S)

Fig. 12: The relationship between the increase in the vibration signal amplitude (V600 Hz) and the technological tool wear indicator (S) for all the tools together
Fig. 13: The relationship between the increase in the noise signal amplitude (N600 Hz) and the geometrical tool wear indicator (VBmax)

Fig. 14: The relationship between the increase in the noise signal amplitude (N600 Hz) and the geometrical tool wear indicator (VBmax) for all the tools together

Fig. 15: The relationship between the increase in RMS of noise signal (NRMS) and the geometrical tool wear indicator (VBmax)

Fig. 16: The relationship between the increase in RMS of noise signal (NRMS) and the geometrical tool wear indicator (VBmax) for all the tools together

Fig. 17: The relationship between the increase in the noise signal amplitude (N600 Hz) and the technological tool wear indicator (S)

Fig. 18: The relationship between the increase in the noise signal amplitude (N600 Hz) and the technological tool wear indicator (S) for all the tools together
CONCLUSIONS

1. The most useful, from tool condition monitoring point of view, was vibration signal (measured by the accelerometer attached to fast headstock of CNC machine tool). The most telling feature of vibration signal was the amplitude visible in the power spectrum of this signal for the narrow frequency range, which was connected with the tool blades passage frequency (600 Hz). All the features of vibration signal which were determined during the time-domain analysis proved to be absolutely useless as a source of information about any aspect of tool wear problem.

2. The diagnostic usefulness of noise (acoustic pressure measured by the microphone) signal turned out to be distinctly lower than the usefulness of vibration signal. One of the most probable reasons of this problem was external noise generated by other machines.

3. Vibration signal as well as noise signal turned out to be evidently better source of information about geometrical than technological indicator of tool wear.

4. Acoustic emission signal, measured by the contact sensor attached to the workpiece, turned out to be absolutely useless as a source of information about any aspect of tool wear problem.

5. In spite of tool wear’s level the conventional cutting gave better quality (less damage of laminate) than the climb cutting.

REFERENCES


Jacek Wilkowski
Warsaw University of Life Sciences – SGGW
Faculty of Wood Technology
Wood Mechanical Processing Department
Nowoursynowska 159
02-776 Warsaw
Poland
Corresponding author: jacek_wilkowski@sggw.pl
Phone: (48 22) 5938577