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Online control of wood peeling process:
Acoustical and vibratory measurements of lathe checks frequency

Louis Denaud(a)*, Laurent Bléron(a), Alain Ratle(b) and Rémy Marchal(a)
louis.denaud@ensam.eu
[a] LABOMAP, ENSAM, rue porte de Paris, 71250 Cluny, FRANCE
tel : +33 (0)3 85 59 53 27
[b] LRMA - ISAT, 49 rue Mademoiselle Bourgeois, 58000 Nevers, FRANCE

Abstract: *In the course of most wood machining processes, operators are usually able to detect various problems simply by hearing the sound emitted by the process. This is especially true for wood peeling. Lathe checks formation has been identified as one of the typical situations that an experimented peeler can detect. Poplar and beech veneer samples have been produced on a laboratory microlathe, using working conditions deliberately favourable to checking. Forces, sound, and vibration levels were measured during the tests. The lathe check frequencies have been determined on both sound and vibration signals using a local Root Mean Square (RMS) averaging and a peak detection algorithm. This makes possible the evaluation of lathe checks distribution along the veneer length. The technique was validated by measuring the real veneer profile using a specific apparatus developed by IVALSA-CNR in Trento (Italy).*

KEYWORDS: Peeling process/Acoustic/Vibration/Lathe checks

Résumé - Contrôle en ligne du déroulage du bois : Mesure acoustique et vibratoire des fréquences de fissuration du placage. *Dans de nombreuses opérations d'usinage, les opérateurs expérimentés sont à même de déceler l’apparition d’un problème en écoutant les sons émis par le procédé. Cela est particulièrement vrai dans le cas du déroulage. La fissuration cyclique du placage a été identifiée comme l’un des phénomènes détectables par les opérateurs sur dérouleuse. Des placages fissurés de peuplier et de hêtre ont été réalisés sur une microdérouleuse de laboratoire, tout en mesurant les efforts, les vibrations et les sons générés par le procédé. Les efforts de coupe sont riches d’informations permettant de caractériser la genèse* *des fissures. Nous avons déterminé les fréquences de fissuration aussi bien à partir des signaux acoustiques que vibratoires en utilisant d'abord une moyenne locale (Root Mean Square), puis un algorithme de détection de pics. Cette technique a été validée par la mesure des fréquences de fissuration à l'aide d'un appareillage spécifique conçu et réalisé par IVALSA-CNR de Trento (Italie).*

MOTS CLEFS : Déroulage/Acoustique/Vibration/Fissurations

1 INTRODUCTION:

Peeling is a wood process largely used for plywood, LVL and packaging production. Due to the shortage of large diameter logs all around the world, industries have to process lower quality logs and species. In the mean time, due to the increasing competition from other materials, e.g. plastic packaging, new procedures should take place in the peeling industry to improve the productivity, the yield and the quality of veneers. Some of the evolving technologies concern on-line diagnosis and control systems. These will help the operators and quality control staff to fine tune peeling lathes in real time.

One of the most comprehensive study was carried out by [14] for the theoretical understanding and modelling of the process. [11] and [4] proposed a program of lathe setting variation issued from force measurements. Those models are very interesting for a better understanding of the settings required to obtain a proper veneer quality but they need a specifically instrumented lathe (which is not the case while using microphones or accelerometers). Moreover, [12] noted that experienced operators are able to set and drive their devices "by the noise". Hence, there must exists an acoustic or vibratory signature in the audible range originating from the mechanics of the peeling process.

To our best knowledge, few works have been realized with acoustic or vibratory sensors as sources of data for wood machining. [13] have found a high correlation between the probability of having a sound pressure level larger than a certain threshold and the surface roughness of the veneer. However, this correlation was better when considering an ultrasonic range (10 to 90 kHz) which doesn’t presumably reflect human sensitivity (the audible range lies between 20 Hz and 20 kHz).

This paper presents a part of the results of a research program intended to evaluate the possibility of using acoustic and vibratory measurements for on-line decision support system [5]. In order to simplify the problem, the microlathe of the LABOMAP at ENSAM (Cluny) was privileged in this first part. Its main characteristics are described by [2]. During all the tests presented in this paper, sound, force and vibration signals have been recorded and no pressure bar was in use.

The first aim of this study is to identify the signatures of typical veneer defects. One of the most important defects regarding the surface quality and handling ability of a veneer is the lathe checks phenomenon. The mechanism of crack generation and growth has been described by numerous authors. It is well known that for homogeneous woods and without pressure bar, the lathe checks frequency and their depths are negatively correlated with the veneer thickness. A specific device developed in the “Non-destructive control” department of IVALSA-CNR has been used to measure lathe checks frequency of the veneers produced with the microlathe.

2 MATERIAL

2.1 The Microlathe

The ENSAM microlathe (*Figure 1*) is a very stiff device which has been specifically designed for peeling tests, cutting force measurements and video observations. First, the tool, the pressure bar and their holders are mounted on two independent crowns. Both are part of a stiff piezoelectric dynamometric system set up on a sliding carriage. Loads exerted by the tools are measured continuously during the tests with geometrical parameters adjustment. The test piece, which is a disk no thicker than 30 mm, is mounted on a gearbox connected to a brushless servo motor. The machining speed range is from 0.01 to 10 m/s.

[FIGURE 1]

The microlathe presents some characteristics required for this kind of experiments. Its stiffness is necessary for the accuracy of vibratory, force or acoustic measurements. The size of the sample moderates the effects of the natural variability of woods without being too far away from a good model of veneer with respect to the wood fibres length. It is assumed that the wood disk properties are constant along its width. This sample format also avoids excessive vibrations occurring at the end of the cutting process, which would be detrimental to the proper identification of lathe checks signature.

2.2 The Acquisition Chain

In order to better capture lathe operator's sensitivity, sensors were selected according to human audible range. Three types of sensors (*Figure 2*) were in use. A capacitor microphone (±0.25 dB between 8 Hz and 12.5 kHz) was fastened to the carriage in front of the cutting edge. This configuration keeps constant the distance between the sound source and the sensor at any time. Microphone position was defined after trials and errors in order to get the best possible signal from the cutting area while taking into account limited space available. Two accelerometers (±1 dB between 0.5 Hz and 17 kHz) were bolted right on the knife to maximise the accuracy of the measure: a first one very close to the cutting edge (the sensor’s mass must be negligible) in the radial direction called Yc and a second one under the knife in the cutting direction called Xc. Due to the extra space required by the Yc accelerometer, a larger knife was designed (60 mm instead of 40 mm) with an usual bevel angle of 20°. This position allows a very high sensitivity to vibrations coming from the cut. Finally, a couple of piezoelectric gauges was prestressed between the small crown and the carriage. These gauges are still in place on the microlathe.

[FIGURE 2]

The sensors have been connected to a multi analyser system (PULSE by Brüel & Kjær). It is an acquisition and signal processing system which makes possible many real time analyses. The sampling frequency was set up to 65536 Hz. This allows an adequate processing of signals for frequencies up to 25.6 kHz according to the Shannon criteria and the real filter capabilities.

3 METHODS

3.1 Trials

Tests have been performed on two 20 mm thick disks free from any visible defect: one from beech and the other from poplar. The samples were stored underwater before the peeling tests. A 20 mm wide and 80 mm long slot was cut on all the disks to determine exactly the start and end points of the veneer peeled during one turn. This way, it is possible to synchronise signal acquisition with observations on the resulting veneer.

Apart from nominal thickness values, all the cutting parameters were kept constant for both species: linear cutting speed of 100 mm/s, zero clearance angle, no pressure bar, room temperature. The knife was previously run in by a 50 m cut at slow speed (0.5 m/s) and with small thickness (0.5 mm). Seven veneer samples were cut for each species with thicknesses respectively equal to 1.3, 1.7, 2.0, 2.3, 2.7, 3.0, and 3.3 mm. Veneers samples were cut after at least one turn around. This procedure ensures that the samples have the nominal thickness and avoids the transient phase occurring during round up. According to the results presented in [6], tool wear influence (especially on lathe checks phenomenon) could be considered as negligible since less than 70 meters of veneer were produced during this experimental campaign.

The veneer samples were numbered and stored underwater before being characterized in IVALSA-CNR. A specific device was designed and realised by Dr. Martino Negri and Dr. Jakub Sandak to measure synchronously the profile of the checked surface with a laser and the effective thickness of the veneer with a LVDT sensor. The measurement principle was to open enough checks to make their detection possible without creating new ones. The apparatus will be described by designers in a following paper. To get an accurate measurement of the profile, the veneers were partially dried. Their density and moisture contents were measured to determine their shrinkage. The data were collected and stored using a Labview application specifically designed for that purpose.

3.2 Lathe check signatures

Figure 3 shows the evolution of both force and vibration signals along the first milliseconds of the peeling of a 2.7 mm thick beech veneer. Because the linear cutting speed was fixed to 100 mm/s, this corresponds to the firsts 12 mm of the veneer. The force signals represented are low pass filtered (Butterworth IIR [3], F_s=320 Hz).

[FIGURE 3]

The cutting force FXc rises to a maximum close to 270 N for a 2 cm width disk. Then, a crack suddenly propagates, because the energy required to create this crack becomes lower than the one accumulated in the veneer under the form of shearing deformation energy. The cutting force FXc, decreases dramatically during the opening of the check. The radial force component FYc decreases also after a small delay. Indeed, the energy required for crack propagation is taken mostly from the FYc component because the veneer still is in contact with the rake face during this phase. Then, the knife starts to cut again with a zero thickness veneer which contributes to the FYc fall. This constitutes a local cutting refusal phase as [14] noticed. Thereafter, the forces increase regularly to reach a new “lathe check formation state”. This means that the cut could be considered as an interrupted process, with each crack propagation phase constituting an excitation of the system. As it was suggested by [8] concerning routing (modelized while using a pendulum), force signals could be used to measure the “cracking frequency”.

The vibratory lathe checks signatures, comparable to an impulse response, are also really easy to identify on both vibration signals. The local maximum of this fast oscillation is most of the time synchronized with FXc drop. Their duration, linked to the damping system, is depending on cutting conditions (cutting speed, clearance angle value) and on device mechanical characteristics. Yc sensor, the closest to the vibration source, is not surprisingly the most sensitive one. The microphone signal, visible on the *Figure 4* (3 mm thick beech veneer) to not overcrowding the *Figure 3*, shows a similar behaviour even if the ratio between peaks magnitude characterizing lathe checks and overall signal level is lower than for accelerometers (*Table I*).

3.3 Lathe check detection

3.3.1 Acoustic and Vibration Measurements

The simplest way to detect lathe checks signature is to count the number of peaks higher than a preset threshold (count rate or cumulative count rate) as suggested by [10]. Nevertheless, this technique is sensitive to signal magnitude variations, and to the arbitrary threshold value. The Root Mean Square (RMS) average of a signal, noted X, is an averaging process proportional to the energy of a signal, rather than to its magnitude:

$$RMS = \sqrt{1/N \sum_{i=1}^{N} x_i{}^2} \qquad \text{for } X=\{x_1\ x_2,\ldots\ x_N\}$$

[10] has also used RMS to get the mean vibration level during cutting. Local information is required to characterize the lathe checks phenomenon. This information is linked to the energy relaxation during crack propagation. That’s why a local RMS average is computed, since it gives a simple representation of the signals’ envelop. The length of the averaging window is determined by the duration of a peak and the number of peaks per unit of time. Both depend on the experimental settings as lathe check itself. To cope with various cutting speeds, everything should be considered in terms of veneer length rather than time units. Several averaging lengths, noted L, were tested. This process is equivalent to searching an optimal measuring precision. The corresponding computing window number *nb* is given by:

$$nb = \frac{L}{Vc * \delta_t}$$

where

Vc: cutting speed (m/s)
δ_t: inverse of the sample frequency (s)
L: veneer length of the averaging window (m)

To be close to the original signal, we determined the local abscissa (*ti*) associated to the maximum of the window denoting the value “*i*”. Then, for each window, the resulting “*i*” point coordinates are (*ti*, *RMSi*). Their drawing is a preset representation of the signal envelop.

Microphone local RMS visible on *Figure 4* is an example for a 3 mm thick beech veneer. This representative example will be discussed later in the paper.

[FIGURE 4]

Together with the RMS averaging, a peak detection algorithm was employed for the detection of the peaks corresponding to lathe checks. This algorithm is based on a gradient hill climbing technique to detect the local maxima in the signals. Each point in the signal is compared to other points in a sliding time window in order to detect the direction of the nearest maxima. The approach employed does not require any predetermined magnitude threshold. This ensures its efficiency for changes in average magnitude signal obtained with different cutting conditions especially thickness variations. *Figure 4* and *Figure 6* present typical results for example previously mentioned respectively for the microphone and Xc accelerometer.

3.3.2 Lathe Checks Measurements

An independent measurement of the lathe check frequency is required to validate the signal processing technique. Since the vibration signatures of lathe checks are related to crack lips opening, it is consistent to measure the distance between the beginnings of each crack. The easiest lip to identify is the second one, following the cutting direction (see *Figure 5*). Indeed, a little flexion of the veneer opens out the checks and makes the second lip stand proud.

[FIGURE 5]

The curve named “profile” on *Figure 6* corresponds to the checked surface measurement of a 3 mm thick beech veneer described as an example in the preceding section. It was obtained using the specific laser device previously mentioned. As it was verified, the shrinkage of the veneer during profile measurement could be considered as homogeneous along the veneer for both species. Simple swelling coefficients were applied to redraw the profile of the veneer at green state.

[FIGURE 6]

Each of the great drops on the signal corresponds to the point where the measuring head passes from the bottom of an opened check to its beginning. The distance between checks is given by the time delay between two consecutive valleys, according to the linear speed of the veneer. To identify these valleys, the signal is low-pass filtered, (Butterworth IIR filter, F_s=200 Hz), then the first derivative is computed before using a valley detection algorithm available on Labview. A series of points "*j*" (*position*, *magnitude*) is obtained, as presented on *Figure 6*.

4 RESULTS AND DISCUSSIONS

4.1 Measurements efficiency

The results shown on *Figure 6* for Xc accelerometer or on *Figure 4* for the microphone are representatives of severe lathe check conditions that can be obtained for thick veneers. The peak detection algorithm that was employed seems to be globally efficient. The large majority of the peaks are easily detected thanks to the local RMS computation that greatly simplifies the problem. The same conclusion holds for the equivalent poplar veneers in terms of thicknesses.

In the same time, even if a very little number of peaks is not well traced back to the local veneer profile, the detection of checks beginning from profile measurement could also be considerate as an efficient technique. Nevertheless, for the thinnest tested veneers (1.3 mm), it was not possible to clearly extract peaks from background noise. A better algorithm has to be found for the detection of very small checks but it was not the purpose of the present study. Consequently, the corresponding profiles are not presented.

As it is shown on *Figure 6*, there is a great correspondence between the check positions (on the *x* axis) obtained while using signal processing and profile measurements. Although they are not always strictly confounded, this point is not a severe drawback of the approach since the check frequency is much more important than the exact position of every check. Indeed, even if a local gap appears between the two signals, it will naturally vanish after a few numbers of checks. The main reason for this comes from the veneer lathe checks measurement. These took place along a line on the veneer, rather than on the whole surface. It was observed that the checks are not always well opened on all the width of the veneer samples. Small amounts of fibres were observed as a bridge over the two lips of some of the checks. This phenomenon is more pronounced on thinner veneers. This is why a few numbers of checks are missing as it can be seen on *Figure 6* around the 70th mm. Moreover, the lip geometry is highly dependent on the local wood structure. For the measurement of a check position on the veneer analysed on *Figure 6*, there could be a more than 1 mm difference between two measures along the two veneer borders. A solution could be the measurement of a real profile to get a 3D representation of the checked veneer surface. Anyway, those gaps cancel each other out when the number of checks detected increases enough. The vibration measurement seems to be less sensitive to these very local phenomena.

[TABLE I]

These observations, and especially the similarity of the two peak detection results, still holds true for Yc accelerometer and microphone signals with a few subtleties. The signal to noise ratios presented in *table I* are given by dividing the average peak levels detected by the overall level of the signal (global RMS). These ratios are almost always higher for beech than for poplar peeling. This reflects what is called the “density effect”. Indeed, the higher density of beech as regard to poplar (basic density respectively reach to 0.571 and 0.436 g.cm^{-3}) requires higher forces level which corresponds to a general trend pointed out by [14] and [15] for peeling process and by [8] and [9] for other cutting process or modes. The energy relaxation during crack propagation is also more important in agreement with the results presented by [1] for ten tropical species in green conditions (basic density ranged from 0.21 to 0.91 g.cm^{-3}). Thus, the induced vibration levels are increased, and the signal to noise ratios improved. It should also be noted that these ratios are usually better for accelerometers than for microphone. This is not surprising since the acoustical signal envelop is not as sensitive to lathe checks formation as accelerometers ones are. It might be possible to use a better adapted mathematical descriptor for microphone signals such as FFT analysis. In the end, all the three sensors sensitivity are positively correlated with the thickness of the veneer (*Table I*). Indeed, the lathe checks phenomenon is also greatly improved when the veneer thickness increases. The degree of this correlation is also better for beech than for poplar due to the density effect which promotes lathe checks formation. Yc accelerometer is the most sensitive sensor. Even if the greatest part of the mechanical excitation is transmitted in the cutting direction, rather than perpendicularly to this direction, the Yc signal was taken very close to the vibratory source and in the direction of the first natural vibration mode of the knife. All these conclusions validate the use of this technique to characterize lathe check frequency.

4.2 The use of lathe checks measurements

[FIGURE 7] [FIGURE 8]

The average values of the distance between two consecutive checks for beech and poplar are respectively pointed out on *Figure 7* and *Figure 8* versus thickness variation. Values issued from both accelerometers signals are almost confused which confirms their sensitivity to lathe check formation. As it was expected, the profile measurement overestimate often a little the distance between checks because some peaks are not detected for the reasons previously developed. The average distance between two consecutive lathe checks which represents the inverse of their frequency is linearly correlated to the thickness variation of the veneer. This is in agreement with the observations presented by [14] for a larger panel of cutting conditions and species. The author introduced Fi, ratio between the average distance between two consecutive lathe checks and the cutting pass. This criterion was found almost constant for a well established lathe check phenomenon.

[TABLE 2]

Table II summarizes the linear regression parameters and theirs associated correlation coefficient we have obtained. Note that the profile measurement fitting was only realized from 6 points (no measurement for 1.3 mm veneers). The quality of the regression is very good (always significant at least 1%) especially for vibration and acoustic measurements. The slope of the straight line, which corresponds to the ratio Fi, is almost constant for the 3 sensors for both species. Moreover, it is higher for poplar than for beech which was not clearly pointed out by [14]. Indeed, the number of checks visible on the veneer is less important for poplar than for beech in case of a relatively thick veneer. When the lathe checks frequency is lower, the checks are deeper as it was observed for homogeneous species. The poplar thick veneers were the most damaged ones (few checks but very deep ones). At the end, even if the origin ordinate has no physical signification, their difference of signs gives interesting information. The negative values obtained for poplar compared to the positive one obtained for beech confirm that the thickness limit of lathe check generation is lower for the beech.

5 CONCLUSION

The use of vibration measurements is well adapted to detect lathe check formation. A simple peak detection algorithm allows a somewhat precise determination of the lathe check distribution along the veneer. It is then possible to evaluate the lathe check rate of the veneer. This technique has to be tested on a larger range of cutting conditions (species, cutting speed, clearance angle, wood heat treatment, pressure rate), but it already shows a great potential utility as a source of information for a decision support system for peeling lathe operators. Indeed, this could be used to optimise the pressure rate especially for heterogeneous species like Douglas fir.

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Table I: The signal/noise ratio values for the three sensors (accelerometers Xc and Yc and the microphone) and its correlation coefficients with thickness variations.

Table II: Linear regression parameters and associated correlation coefficient for average distance between two consecutive checks *vs* veneer thickness for both species and all sensors.

Figure 1: The instrumented Microlathe.

Figure 2: Sensors disposition.

Figure 3: Lathe checks signature on both vibrations and forces signals in tangential and radial direction for a 2.7 mm thick beech veneer.

Figure 4: Original, preset and peak detected from the microphone signal for a 3 mm thick beech veneer.

Figure 5: Beech checked veneer.

Figure 6: Peaks detected on both preset vibration signal Xc and veneer profile from laser sensor for the first 100 mm of a 3 mm thick beech veneer.

Figure 7: Average distance between two consecutive checks measured by accelerometers, microphone and laser *vs* veneer thickness for beech.

Figure 8: Average distance between two consecutive checks measured by accelerometers, microphone and laser *vs* veneer thickness for poplar.

TABLE I

Thickness (mm)		**1.3**	**1.7**	**2**	**2.3**	**2.7**	**3**	**3.3**	**r^2**
Beech	***Xc***	1.484	1.593	1.640	1.678	1.694	1.713	1.832	0.916
	Yc	1.585	1.636	1.653	1.711	1.751	1.779	1.906	0.932
	Microphone	1.259	1.295	1.326	1.363	1.420	1.430	1.512	0.973
Poplar	***Xc***	1.329	1.441	1.458	1.456	1.478	1.723	1.805	0.821
	Yc	1.384	1.525	1.528	1.531	1.572	1.808	1.874	0.850
	Microphone	1.207	1.248	1.238	1.250	1.179	1.338	1.379	0.459

TABLE II

	Beech		***Poplar***	
	Linear Regression	**r^2**	**Linear Regression**	**r^2**
Xc	*Y*=0.963 *t* + 0.172	0.982	*Y*=1.397 *t* - 0.446	0.990
Yc	*Y*=0.966 *t* + 0.163	0.983	*Y*=1.391 *t* - 0.446	0.990
Microphone	*Y*=0.930 *t* + 0.282	0.980	*Y*=1.189 *t* - 0.040	0.992
Profile measurement	*Y*=0.824 *t* + 0.669	0.901	*Y*=1.416 *t* - 0.294	0.975

FIGURE 1

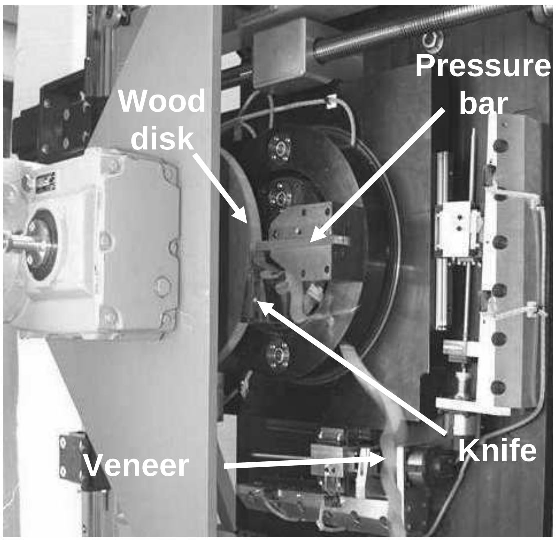


FIGURE 2

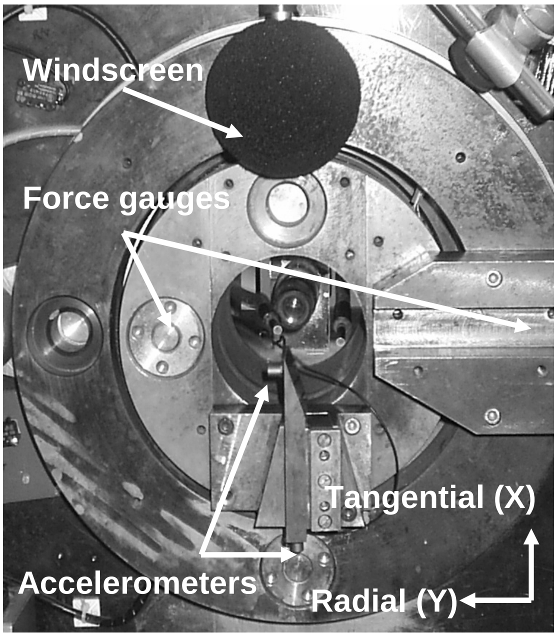


FIGURE 3

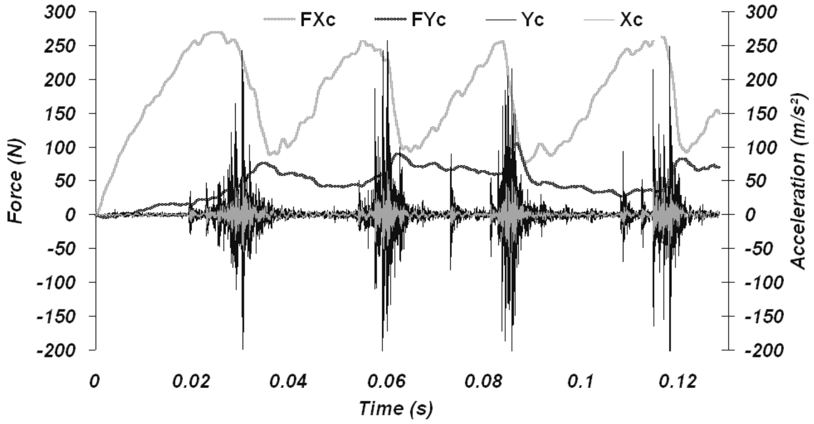


FIGURE 4

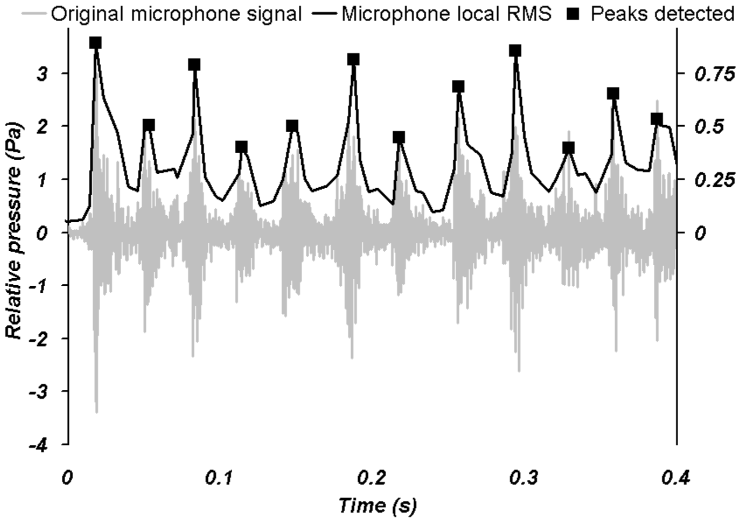


FIGURE 5

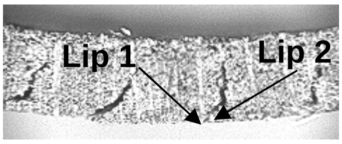


FIGURE 6

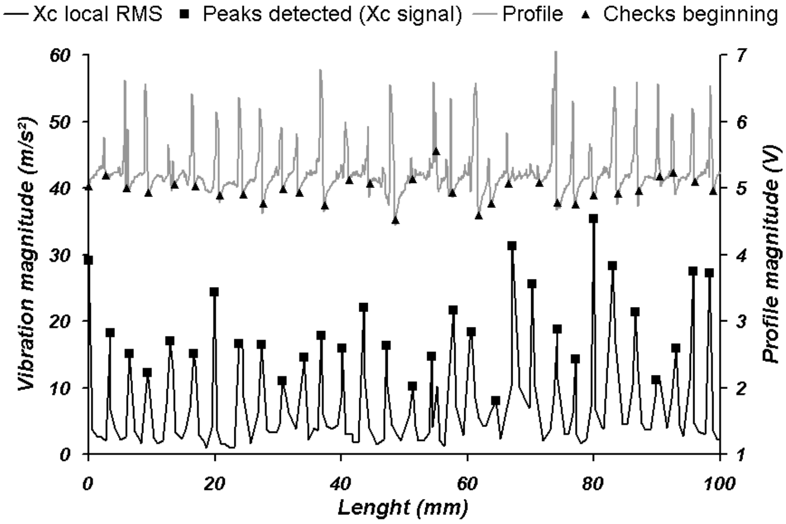


FIGURE 7

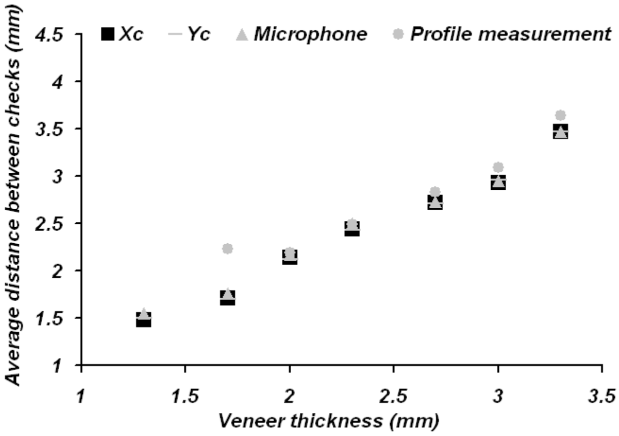
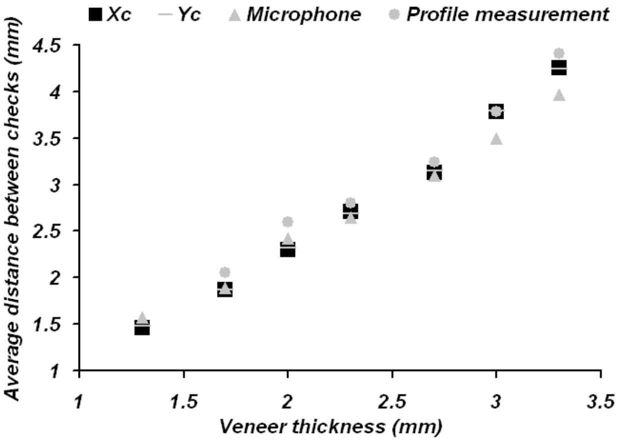


FIGURE 8


■ Xc
— Yc
▲ Microphone
● Profile measurement
Average distance between checks (mm)
4.5
4
3.5
3
2.5
2
1.5
1
1
1.5
2
2.5
3
3.5
Veneer thickness (mm)