Vibro-acoustic of table tennis rackets. Influence of the blade plywood design. Experimental and sensory analyses

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Abstract :

The performances of a table tennis racket can be qualified with several adjectives like: fast, slow, stiff, adhesive, controllable, etc. These qualifications are subjective since they are relative to the sensory analysis made by each player. It appears that the noise produced at the ball impact on a racket has a great influence on the opinion that a player can give about a racket. Moreover, the sound emitted at the stroke can be appreciated differently among several players. Hence a good sound may give a positive a priori to the player abut the racket appreciation.

The work presented first demonstrates the correlation between the acoustic frequency spectrum and the vibration frequency spectrum of a racket following the ball impact. The analysis is first performed on the racket blades without rubbers glued on. The vibration modes that produce the sound at the ball impact were identified experimentally. It is shown that two main vibration modes are responsible of the sound emitted. In second, the influence of the blade plywood composition is studied. Several prototype racket blades have been designed with some differences between them on: the thickness of the plies, the wooden essences. The experimental results obtained permit to clearly state on the effectiveness of these design parameters on the impact sound.

In the last part of this study, the experimental observations obtained at the laboratory are compared with the results of a sensory analysis performed with the same prototype rackets by a panel of high level players. It is shown that the classification made by the players is consistent with the experimental laboratory observations.

Keywords : Vibro-acoustic, table tennis racket, ball impact, plywood composition, sensory analysis

1 Introduction

The perception of the table tennis racket performances depends on many factors. Most of the appreciations formulated by confirmed players are subjective since they are relative to their proper sensory analysis. Usually, the rackets can be qualified as fast, slow, stiff, adhesive, controllable, etc. It can happen that two players of same level will give contradictory opinion for the same racket. The acoustic signature at ball impact is the first appreciation element of the racket performances; therefore it has to sound well in order give a positive a priori for the other evaluation parameters.

This work is in the continuity of a previous study that had analyzed the vibratory behavior of racket blades and the associated specific finite element modeling of the plywood. The vibration modes were simulated and correlated satisfactorily with some experiments. The study presented here is concerned with the vibro-acoustic of tennis table racket at ball impact. First, the correlation between the structure and the acoustic vibrations is demonstrated. The structure vibration modes that produced the sound at ball impact were identified. Then, several racket blade prototypes have been realized to study the influence of the racket blade plywood composition on the vibro-acoustic behaviour. The blade plywoods tested differed by the thickness of the plies and/or their wood essence. In parallel, a sensory analysis had been conducted with some high level players. Finally, the sensations of the players are analyzed versus the laboratory test results obtained.

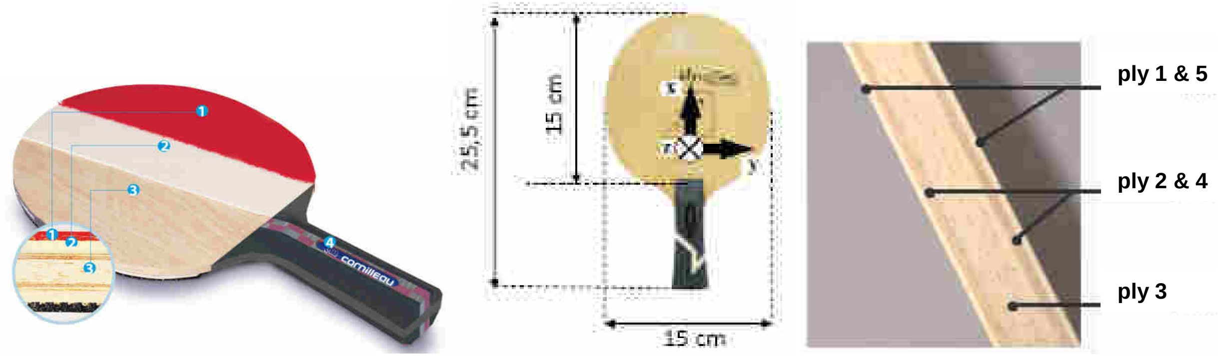


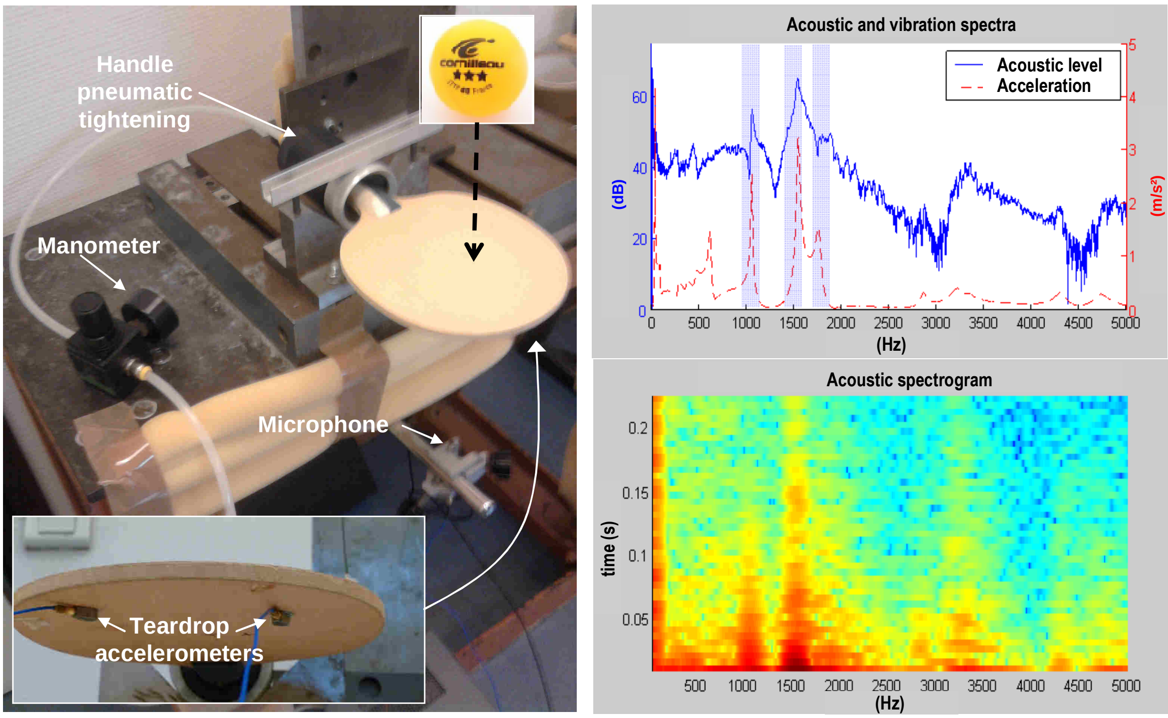
FIG. 1 – Table tennis racket (a), blade (b), blade plywood composition (c)

The ball-racket impact in table tennis had been studied in many works from the restitution coefficient point of view, the main results and ideas can be found in [1, 2]. To our knowledge, there is no published work on the vibro-acoustic of tennis table racket. Nevertheless, several informations can be found and read on some internet forums and blogs edited by players.

2 Vibro-acoustic at ball impact

2.1 Experimental set up

The racket handle is tightened with a pneumatic membrane that reproduces the tightening of a player hand, the air pressure is fixed to 5 bars and controlled by a manometer (Fig. 2a). The ball is dropped over the racket from a height of 0.9 m with a zero initial speed, this leads to an impact velocity of 4.2 m/s. It is guided in a tube during the first 20 cm of fall to insure the repeatability of the impact point.



(a) (b)

FIG. 2 – (a)Test device, (b) Acoustic and vibration spectra after ball impact on a racket blade, spectrogram

Two teardrop accelerometers (PCB 352A21) are glued on the back of the racket. A microphone (PCB T130D21) is placed at 0.2 m distance from the racket. The sensor signals are recorded and analyzed using a data acquisition system (Oros 35). It was observed that the air pressure applied in the pneumatic tightening had a little influence on the acoustic frequency values, i.e. a difference of 3 bars can lead to a change of 30

Hz which corresponds to a height note change (ex: La 440 Hz, La# 466 Hz). This explains why for one racket, depending on the force the player hand tights the handle, the acoustic at ball impact can be changed and therefore appreciated differently. The spectra of the acoustic pressure and acceleration are plotted (Fig. 2b), the evolution of the acoustic spectrum versus the sound duration time is visualized by means of a spectrogram.

The tests carried out on the racket blades aimed at characterizing their vibro-acoustic behavior at the ball impact, i.e. from the acoustic and vibration spectra to see if any correlation existed. At first, only the racket blades were tested, i.e. without rubbers. As it can be seen on the figure 2b the racket vibration and acoustic spectra are composed of the two same dominant frequencies. Hence, one can see that there is a direct correspondence between the vibrations of the racket blade and the sound produced at ball impact. The tests performed on the racket blades with the rubbers glued on have led to the same type observations but the frequencies are decreased by 30%.

2.2 Influence of the racket plywood composition and design

In parallel to the vibro-acoustic analysis, a modal analysis has been conducted using a laser vibrometer (Fig. 3). The racket blade surface is meshed to define the measurement points. A shock hammer is used to hit the racket at the ball impact point on the back of the scanned surface. The measurement was trigged on the shock hammer signal and repeated three times for each point, and then an average value was stored. Once all the points of the mesh are scanned, the vibrometer software is able to rebuild the vibration behaviour of the racket blade for any given frequency. Hence the modes associated with the resonance frequencies of the structure can be visualized.

This modal analysis combined with the vibro-acoustic tests has permitted to identify the modes corresponding to the dominant frequencies of the vibro-acoustic spectra. Hence the vibration modes that produced the sound at ball impact have been named the chips and membrane modes (Fig. 2b & 2c). Following the ball impact, the racket blade vibrates and its vibration behaviour results in a combination of its vibration modes. The chips and membrane modes excite the air molecules that vibrate and produce the sound.

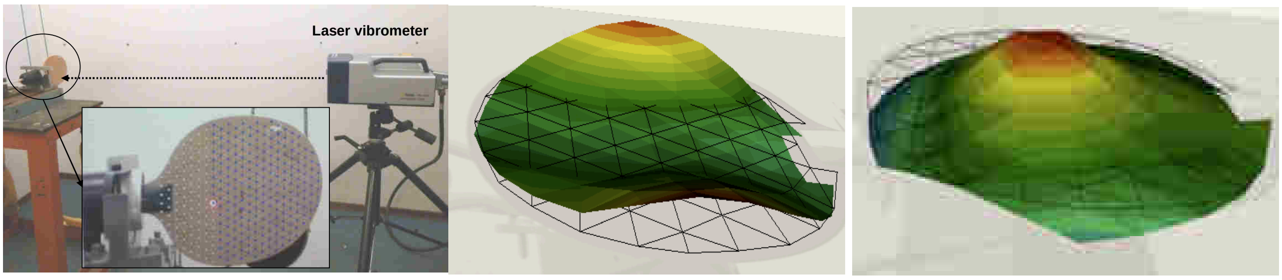


FIG. 3 – (a)Vibrometer test apparatus, (b) Chips mode, (c) Membrane mode

It can be found in the literature that the resonance frequencies of a circular plate of diameter D and thickness h, are given by:

$$\omega_i = A_i \sqrt{\frac{E.h^2}{\rho.D^4.(1-\upsilon^2)}} \quad (1)$$

where, E is the Young modulus, ρ the density, υ Poisson ratio, A_i a constant depending on the boundary conditions and the vibration mode. From Eq. 1, it appears that the resonance frequencies depend linearly on the plate thickness h and also non linearly on the material elasticity via E. As the plywood of a racket is non homogeneous (several plies and wood essences) some test sample rackets have been realized in order to analyze the influence of the ply thickness and/or essence on the vibro-acoustic of a table tennis racket at ball impact. The racket samples are grouped by set so that only one parameter is varying in the set. The plywood compositions of the tested rackets are given in table 1, the essence of each wood layer and its thickness are detailed. The longitudinal Young modulus of the wood essences are given in table 2.

Name	Wood essence	Thickness
Set 1 : Essence of ply 3	Kiri Ayous Balsa	3,6 mm
Set 2 : Thickness of ply 3	Kiri	3 mm 3,4 mm 3,8 mm
Set 3 :Thickness of plies 2 & 4	Ayous	0,4 mm 0,6 mm 0,8 mm
Set 4 : Essence of plies 2 & 4	Limba Akazie Pine	0,6 mm

TAB. 1: List of tested rackets grouped in 4 sets

Wood essence	E (MPa)
Akazie	16900
Ayous	7260
Balsa	5140
Hinoki	10145
Kiri	4500
Koto	13140
Limba	11750
pin	11000

TAB.2: Young Modulus of wood essences

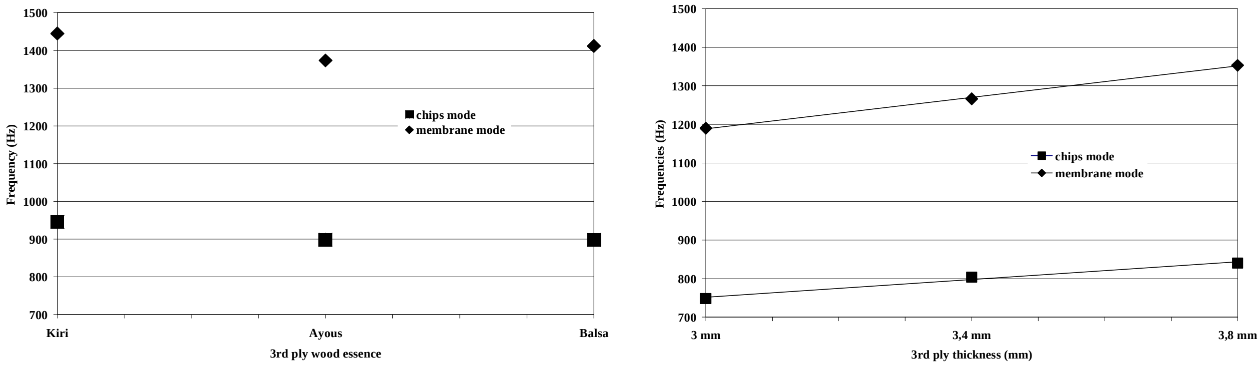


FIG. 4 – Variation of the vibration frequencies for :(a) different wood essences of ply 3 , (b) different thickness of ply 3

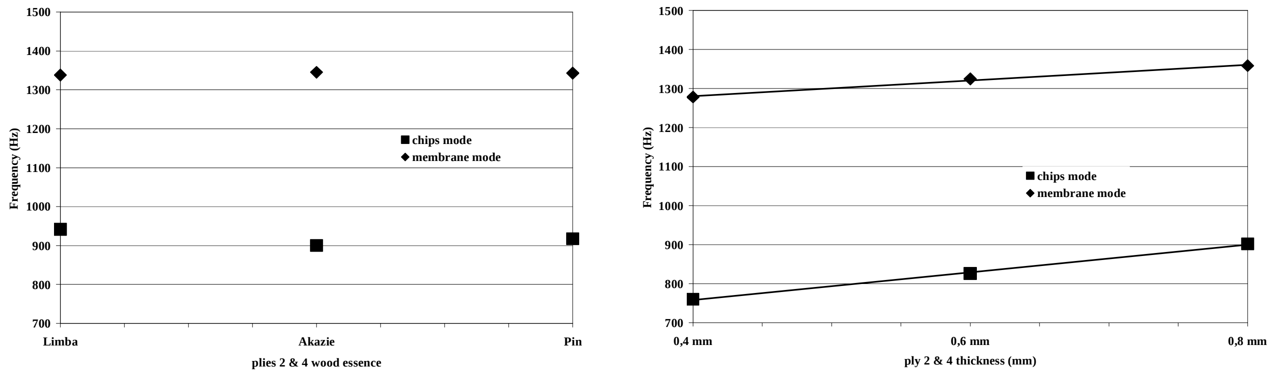


FIG. 5 – Variation of the vibration frequencies for:(a) different wood essences of plies 2 & 4 , (b) different thickness of plies 2 & 4

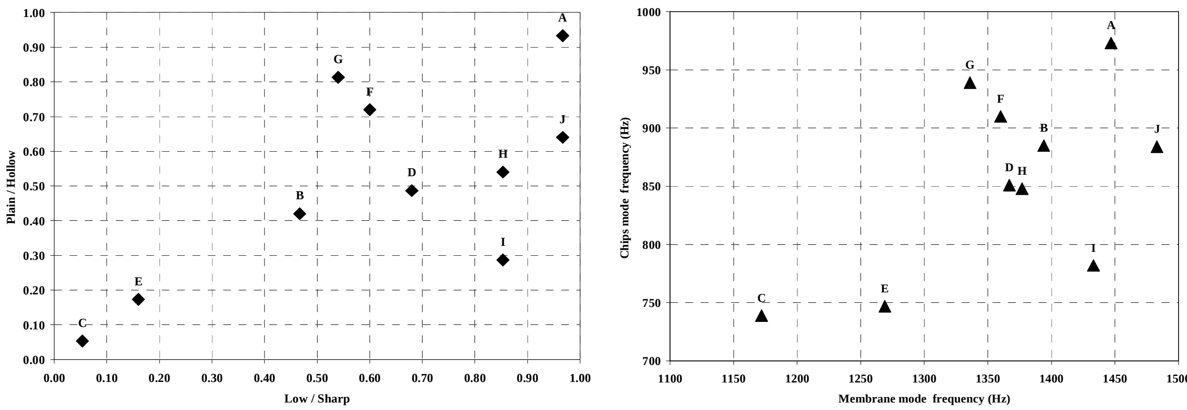
It can be seen on figures 4a and 5a that the wood essences of the plies 2 and 3 have some unexpected little influence on the vibration frequencies of the racket blades. One could have expected that a stiffer wood would correspond to a higher vibration frequency, but it is not that clear from the experimental results. However, it is demonstrated that the thickness of the plies influence the frequencies of the two main vibration modes (FIG. 4b and 5b). It is confirmed that the vibration frequencies vary linearly with the ply thickness.

2.3 Laboratory experiments vs. sensory analysis

A sensory analysis has been conducted in order to study if there is any correlation between the vibro-acoustic laboratory experimental results and the player opinions on the rackets tested. Ten racket blades have been selected for this analysis, their measured vibration frequencies are given in table 3. The same rubbers were glued on all rackets, and some tape was stuck on the blade edge so that all the rackets look identical. Seven players were asked to classify the rackets by their sound similarity in a two dimensions space: plain/hollow sound and low/sharp sound. Three players have given a non consistent sensory analysis, i.e. for each of them there was no repeatability observed for a same racket tested, therefore they were not taken into account in the synthesis. The results presented in figure 6a correspond to a synthesis made among four players for which the sensory analyses were estimated reliable.

Racket	Model	chips mode (Hz)	membrane mode (Hz)
A	Ply 3 – KIRI 3.6 mm	973	1447
B	Ply 3 – BALSA 3.6 mm	885	1394
C	Ply 3 – KIRI 3 mm	739	1172
D	Ply 3 – KIRI 3.8 mm	851	1367
E	Ply 2 – AYOUS- 0.4 mm	747	1269
F	Ply 2 – AYOUS - 0.8 mm	910	1360
G	Ply 2 – LIMBA – 0.6 mm	939	1336
H	Ply 1 – 1 mm - AYOUS	848	1377
I	Ply 1 – HINOKI – 0.6mm	782	1433
J	Ply 1 – KOTO 0.6 mm	884	1483

TAB. 3: Frequencies of the chips and membrane modes for the rackets used in the sensory analysis.



(a) (b)

FIG. 6 – (a) Classification of the racket sounds , (b) Visualization of the racket vibro-acoustic frequencies

In figure 6b the rackets are positioned with their coordinates in the membrane-chips frequencies two dimension space. The distributions of the rackets in the two figures 6a and 6b show some similarities. It appears that the appreciations of the players about the sound at ball impact are consistent with the vibro-acoustic laboratory experimental results. Moreover it can be observed that the membrane vibration mode of the racket blade is associated with the sharpness of the ball impact sound, whereas it seems that the chips vibration mode corresponds to the plain or hollow classification.

3 Conclusion

This study has shown experimentally that there is a correlation between the vibration and the acoustic behaviours of a table tennis racket blade at ball impact. Two vibrations modes are mainly responsible of the racket acoustic, they are named the chips and membrane modes. Each racket tested has been characterized by its acoustic and vibratory signatures. Some modal analyses using a laser vibrometer were performed on the racket blades to clearly identify the vibration modes.

The composition of the plywood has a great influence on the vibro-acoustic spectrum and consequently on the sound produced at ball impact. Some test sample rackets have been realized in order to analyze the influence of the ply thickness and/or essence on the vibro-acoustic of a table tennis racket at ball impact. The racket samples were grouped by set so that only one parameter was varying in the set. It was shown that is more the thickness of each ply of wood that influences the vibro-acoustic than the wood essence used. The vibro-acoustic frequencies of the racket blades vary linearly with the increase of the ply thickness.

A sensory analysis, implying high level players, was conducted. The players were asked to classify the rackets by sound similarities for two criteria: plain/hollow and low sharp sound. The comparisons between the sensory analysis and the vibro-acoustic laboratory experimental results show a good consistency. Moreover it is shown that the ball impact sharpness is related to the membrane mode vibration frequency of the racket blade.

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