1 Introduction

One of the great mysteries of the violin making is how the renowned violinmakers of past centuries, apparently having had no more than a practical knowledge, could turn out violins that are still cherished today for the beauty of their sound.

The quality of bowed musical instruments depends on the properties of material. Violinmakers have always known that selection of wood makes the difference in quality violins. Maple is preferred for the back, ribs and neck, while spruce is preferred for the top plate. At the evaluation of material quality is important to know, which physical properties are most important to the sound of a fine instrument.

Wood as a material in the musical instruments making has to satisfy some technical and aesthetical parameters. The most important characteristics of wood used in the violin making are: density – $\rho$, Young’s modulus of elasticity – $E$ and acoustical constant – $A$. These characteristics are called physical and acoustical characteristics (PAC) of wood.

The three dimensional graphic representation $(\rho, E, A)$ has been shown as a tool giving the objective results for wood grading from the viewpoint of its using for a special purposes [3].

The secret of old master – luthiers is searched with help of modern methods. This way is slow but the most effective. New tests of the vibrational properties of the unassembled top and back plate of violin reveal something of what violinmakers do by “feel”. Taylor from Kingdom institute in Great Britain said: “Scientifically speaking, I think we are beginning to help makers to achieve more uniform instruments. We are not necessarily helping them all to achieve the quality of Strad is, for example, because we frankly don’t know what the real quality of Strad is”[2].

In this contribution are presented results of tuning process for free plates by monitoring of the vibrations rectangular boards and the free top and back plate of violin without and with $f$-hole by Chladni patterns.

2 Theory

2.1 Material from point of view of violinmakers

At first is important visual evaluation of resonant spruce wood and curly maple wood. Resonant spruce wood has the annual rings width 0, 1 – 2, 5 mm, maximum 3, 5 mm, i.e. 3 rings in 1 cm [4]. The ratio of earlywood to latewood is important and also the colour, which have to be white, without wood knot and resin. The percentage of latewood in whole volume of resonant wood is about 20 %. The annual rings have to be approximately equal and the grain parallel to axis of...
the trunk. Maple wood (Acer pseudoplatanus L.) usually have a “flame”, or “curly”, across the grain of wood.

The next criterion is uniformity and thickness of annual rings. The resonances of a plate violinmakers detected by taping and listening as on Fig. 1.

2.2 Physical and acoustical characteristics of wood

Visualization of modes in the thin plates is possible by Chladni patterns. According to this non-destructive method we can measure elastic properties of wood, what is used in musical instrument making, e.g. for violin making. By the Chladni method normal mode patterns of vibration of a horizontally mounted plate can be measured resonance frequencies. These plate resonances are created by the physical properties of stiffness and mass, which cause standing–wave patterns to be formed in response to vibration at discrete frequencies unique to each plate. This method allows find resonance frequencies and to compute values of relevant PAC.

Density is important characteristic of wood as a material for musical instruments making, density is given by formula [8]:

\[
\rho_w = \frac{m_w}{V_w}
\]  

(1)

The formulas for calculate of modulus of elasticity \( E_x \) in a free rectangular orthotropic plate for bending beam vibration (2, 0) mode [6] are given as:

\[
E_x = D_i, 12 \eta ; \quad D_i \approx 0,0789 \frac{f^2}{h^4} \rho a^4 ; \quad \eta = 1 - \mu_{xy} \mu_{yz}
\]

(2)

The acoustics constant \( A \) is given by relation [1]:

\[
A = \frac{\sqrt{E}}{\rho} = \frac{c}{\rho}
\]

(3)

2.3 Tuning the violin plates by Fuhr pipe method and Chladni patterns

The both methods, Fuhr pipe method and Chladni patterns, nearly cooperate because they are resonant methods and generally are used by violinmakers.

The new in Fuhr pipe methods is using glass pipe for excitement tone during violin plate making, also for excitement of tone on final musical instruments. If the glass pipe is equally light, the mistake will be (by influence of its weigh) nominal as in excited tone on plate, also on final musical instruments. If we are exciting basic tone of plate, catch the plate lightly on the corners between thumb and forefinger, alternatively middle finger, where is centre of gravity of plate. Glass pipe we catch in its top part and fit approximately in place of the bridge, wet both thumb and forefinger move down to the plate until the moment when the tone is loudly (pipe have to be sealed at the end, alternatively with little stopper made from hard rubber). Usually, tone of plate is decreasing by gradual reducing the thickness. Because most of tones from interval can be sounded, not only single tone, always is possible to define, which tone is basic. The basic tone is not able to sounding immediately, but it can be sounded after in some other test of excitement. Basic tone is important, because is excited on centre part of plate in place, where is main vibrations of final violin body. The basic tone of resonant top plate is decreasing about half tone due to engrave of "f" holes. Therefore is considered to follow basic tone of top plate, its weigh and thickness, only on plate with final engraved "f" holes. More tones still exist on various parts of plate, which is possible to follow. Also these tones have their signification [7].

The method of Chladni patterns visualise modes in thin plates. At certain frequencies the vibration bounces the powder into the non–vibrating nodal areas, thereby outlining the nodal and antinodes configurations of the plate at specifics resonance frequencies. Shape of nodal line depends on symmetry and homogeneity of plate and its dimensions. Symmetrical plates show symmetrical distribution of nodal line. In case of non–homogenous structure of plates are created non–
symmetrical Chladni patterns, alternatively at all uniformed. Shape of nodal lines depends on the plate dimensions.

For violins plates tuning are modes 1, 2 and 5 the most important as Fig. 2. These modes are the best observed on free violins plates. Mode 1 is twisting of plate. When one single edge is up, the other are down, they vibrate in opposite phase. Than there is frequency around 90–130 Hz. Mode 2 is vibration of sides in phase, against of centre and low and top edge. Tones about in octave higher than mode 1, it corresponds to mode 2. Mode 5 corresponds to basic tone of plate. There was frequency 340–370 Hz. Mode 5 of top plate is oscillating in opposite phase with edges.

Figure 2.: Modes 1, 2 and 5 of violins plates

3 Experiments

3.1 Material

Experimental samples were cut out from maple (Acer pseudoplatanus L.) and spruce (Picea abies) logs from various locality of Slovakia. The trunks of experimental material were divided into four parts by perpendicular cuts parallel to the axis of the trunk. Then the wedges were precisely radially cut out (quarter-cut). Spruce samples respond to visual characteristics and empirical experience of violinmakers. Curly maple wedges was characterized by lover quality of grain waves. The wedges were air dried for four years in wood stock. The wedges were storage in laboratory room last year. The moisture content of samples was running determined by weighing method (moisture content was \( w = 8 \% \pm 1 \% \)).

3.2 Apparatus

For measuring and indication modes by Chladni patterns was used equipment VIBROVIZER (Fig. 3) After calculation of density from the measured data of samples were found out frequency of modes stand bending waves. Signal is transmitted to loudspeaker by amplifier and tone generator. Tone generator tunes frequency caused own vibration of wedges and plates. Acquired data account computer.

Figure 3.: Equipment for Chladni patterns (1 – plate, 2 – vibration of plate, 3 – Chladni pattern)

3.3 Results

PAC of samples are given by formulas (1)–(3). Average values of PAC spruce and maple wood are presented in Tab. 1. Those samples were used to making experimental violins.

The visualization of modes and measuring resonant frequencies was realized by equipment (Fig. 2).

In the first part of experiments were measured the top plate without “f” holes and bass bar. With VIBROVIZER and progressive removal of material from inside of plate was looked resonance frequency of mode 5. (311Hz). This corresponds with basic tone Dis in tuning by Fuhr pipe [6]. Indication powder created figure (Fig. 4).
Table 1: Average values of density $\rho$, modulus of elasticity $E$ and acoustical constant – $A$ experimental spruce and maple wood and compared with average values of standard ($w = 8\%$).

<table>
<thead>
<tr>
<th></th>
<th>$\rho$ [kg.m$^{-3}$]</th>
<th>$E$ [GPa]</th>
<th>$A$ [m$^4$.kg$^{-1}$.s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>maple</td>
<td>566</td>
<td>12.49</td>
<td>8.32</td>
</tr>
<tr>
<td>standard maple</td>
<td>613</td>
<td>11.50</td>
<td>7.18</td>
</tr>
<tr>
<td>spruce</td>
<td>409</td>
<td>12.03</td>
<td>13.19</td>
</tr>
<tr>
<td>standard spruce</td>
<td>430</td>
<td>13.80</td>
<td>13.16</td>
</tr>
</tbody>
</table>

- Standard maple – maple of high quality for master violin making
- Standard spruce – resonant spruce wood for master violin making

In the second part of experiments was measured top plate with “f” holes and without bass bar. Frequency declined about 20–50 Hz. It corresponds with basic tone D to C in tuning by Fuhr pipe (PILAR, ŠRÁMEK, 1986). In this part was measured second mode (frequencies 116–120 Hz). Indication powder created figure (Fig. 5), what is mode 2.

In the third part of experiments was measured the top plate with “f” holes and with bass bar. The frequencies of mode 5. of free top plate were 317–330 Hz. The frequencies of the second mode were 146–155 Hz. Completely finished the top plate with the fifth mode is on the Fig. 6.

In the forth part of experiments was measuring of the back plate. It would by the best if frequencies of the mode 5. of back plate are 340–370 Hz. The second mode frequencies are in octave down [5].

The results of our experiments indicated frequencies of the mode 5. on the back plate is around 375 Hz, and the second mode is 177–180 Hz.

Table 2.: Measured frequencies of the basic modes of violins plates

<table>
<thead>
<tr>
<th></th>
<th>spruce top plate</th>
<th>maple back plate</th>
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<tbody>
<tr>
<td>without “f” holes</td>
<td>311 Hz</td>
<td>330–317 Hz</td>
</tr>
<tr>
<td>with “f” holes</td>
<td>291–261 Hz</td>
<td>375 Hz</td>
</tr>
<tr>
<td>with bass bar</td>
<td>120–116 Hz</td>
<td>180–177 Hz</td>
</tr>
</tbody>
</table>

- The frequencies of two basic modes of spruce top and maple back plates in various steps of violin plates making.

4 Discussion

Standard spruce and maple wood was received from well-known Czech violinmaker. The results of PAC were obtained from measuring the stick samples cut from original plates for top and back of high quality material. The sets of the PAC values of standard spruce and maple species could be used for comparison with values of different sets of a measured experimental material. Properties of the test material should be explored for the sake of potential utilization for violinmaking.
From the results presented in Tab. 1, standard curly maple, which is usually applied to the violin back plate, has higher density, lower acoustical constant and lower modulus of elasticity in comparison to the experimental samples of maple. Standard spruce wood, which is usually applied to the violin top plate, has higher density, higher modulus of elasticity and approximately the same value of acoustic constant in comparison to the experimental samples of spruce wood. From the point of view PAC, the experimental samples indicated lower quality of material for violinmaking in compared to standard. From the aspect of violinmaker, our experimental samples also indicated lower quality of wood, but spruce wood can be used for the best quality of violinmaking. On the other side, maple wood cannot be used for making of master instruments.

As presented before frequencies of the basic modes are important in process of tuning of the violins plates achieved according C. M. Hutchins method [4].

The tuning of the top spruce plate is more difficult than the back plate because “f” holes and bass bar is added. Our experimental spruce plates without “f” holes and bass bar was tuning on 5.mode with frequencies 311 Hz (tone D#). This fact corresponds with references [4,6]. The tuning spruce plate with “f” holes and without bass bar was realized on 5.mode with frequencies 260–280 Hz (tone C – D). This fact also was responding with references but 2.mode was not in octave down.

After add the bass bar the resonant frequencies of spruce top plate were from the range 317–320 Hz. The second mode with frequencies (155–146) Hz was not in octave. Complete spruce plate with "f" holes and bass bar was tuned down according the references. Probably, this fact was caused by incorrect made of bass bar.

The tuning of maple back plate was corresponded with references. The resonant frequency of 5.mode our experimental back plates was 375 Hz and 2.mode from the range (180–177) Hz.

5 Conclusion

From our experimental measurements it could be concluded that:

1 – from point of view violinmakers, our experimental samples indicated lower quality of material for violin making, exceptional the spruce wood, which has uniform structure of wood grain;

2 – from point of view physical and acoustical characteristics, our experimental samples indicate lower quality of material for violin making, exceptional the spruce wood, which acoustical constant is comparable with standard spruce wood value;

3 – from point of view the tuning of plates (Chladni patterns and Fuhr pipe), our experimental top spruce plates was finally with bass bar tuned down, back plates was corresponded to general demands;

In the end, the tangible results has been achieved, the experimental violin has been assembled, we can see on (Fig.7).

Figure 7.: Violin of Strad model and folk acoustical guitar Dreadnought

References


