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PHYSICO-ACOUSTIC CHARACTERISTICS OF SPRUCE AND LARCHE WOOD

Pavol Halachan, Marian Babiak, Dominik Spišiak
Technical University in Zvolen, Faculty of Wood Science and Technology
Department of Wood Science Zvolen
Department of Fire Protection
Zvolen, Slovak Republic

Anatoly N. Chubinsky, Alexander A. Tambi, Kirill V. chauzov
Saint Petersburg Forest Technical University, Faculty of Mechanical Wood Technology, Department of Wood Sawing and Drying
Saint Petersburg, Russia

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ABSTRACT

This study deals with non-destructive measurement of wood, i.e. physico-acoustic characteristics (density, dynamic modulus of elasticity, acoustical constant, speed of sound propagation in material and logarithmic dumping decrement). We used two species spruce and larch for measurements. We took wood from two main areas: from Slovakian higher latitudes and from Russia - Siberian areas. Spruce is the main species for the boards of musical instruments and we tried to find another species to replace this one. We measured physico-acoustic properties by two devices: The ultra-sonic tester and device "MEARFA" based on searching correct frequency for each sample. The results show that spruce for top instruments has acoustic constant approx. 12 $m^4 \cdot kg^{-1} \cdot s^{-1}$ and the "best" value for larch was approx. 10 $m^4 \cdot kg^{-1} \cdot s^{-1}$. If we compare the methods of measurement of the sound velocity through samples the results for ultrasonic testing are much higher than those provided by resonance-dynamic method. The article also describes differences between physico-acoustical characteristics of sap wood and heart wood, and differences between species.

KEYWORDS: Larch, Spruce, Ultrasound, Resonance dynamic measurement, Acoustic constant

INTRODUCTION

Non-destructive testing of materials is very important for measuring acoustic-mechanical properties of material. Ultrasonic testers are very useful in engineering industry for testing the quality of welds. With this technique it is possible to get indirect information about the condition of the wooden construction unit or internal damage from the received signals (Hasenstab et al. 2005). According to other authors (Bucur 1983, Sandoz 1996, Senalik et al. 2014, Tanasoiu et al. 2002) we can also find a lot of studies about checking the health of living trees and applications of ultrasonic sound in industry. The resonance methods, for example modal analysis using of Chladni patterns (Fig.1), are used for finishing top boards of musical instruments. This top must have a high value of acoustic constant. This quality number for wood describes possibilities of wood to make sound louder without distortions of tones. This means that for this method we need board material to see figures (modes) of correct tuned frequency.

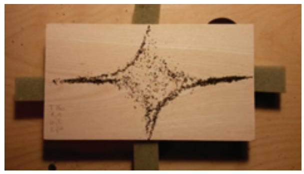

Fig. 1: Modal analysis – Chladni patterns.

The resonance dynamic method is based on measuring of the rods in one direction much higher than the other two. This method is also non-destructive but if we compare it with non-destructive method we need to have samples for the device. Ultrasonic is very simple because we only put two probes on the beam and the measurement is very fast.

MATERIAL AND METHODS

We used for experiments Siberian larch (*Larix sibirica* Ledeb.) which is the most common in Russia (Fig. 2), European larch (*Larix decidua* Mill.) and Norway spruce (*Picea abies* L.). The spruce logs (for ultrasonic tester) harvested in the Vyborg district of Leningrad region at maturity - 80 - 120 years. We cut from chosen sections samples with dimensions 20×20×300 mm (for ultrasonic tester) and 10×10×400 mm (for MEARFA) (Fig. 3). The equilibrium moisture content of measured samples was 8% ±1%. The eight percent is the most common moisture content for instruments making and using.

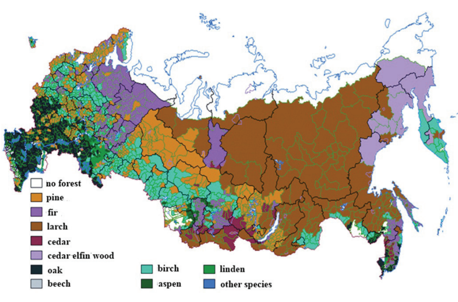

Fig. 2: Tree main species in Russia (Annual report 2012).

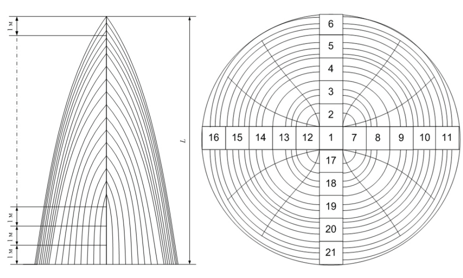

Fig. 3: The scheme of cutting sections (Chubinsky et al. 2002).

We used the fallowing devices for our measurement (Fig. 4, 5). The timing of the passage of sound vibrations determined by ultrasonic device UK-14P designed to measure the time of propagation of longitudinal ultrasonic waves and rise time of the entry of the first signal (Fig.4).

Tab. 1: Properties of ultrasonic tester.

Characteristics of ultrasonic tester	Value
The range of time measurement of ultrasonic vibrations	20 – 8800(*μsec*)
Measuring range rise time of the first entry received signal	3 – 30 (*μsec*)
Absolute sensitivity	110 (*dB*)
The amplitude of the pulse generator	320 + 50 (V)
Supply voltage	4.5 (*V*)

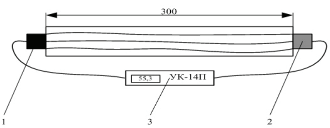

Fig. 4: Ultrasonic tester UK-14P (УК-14П): 1 - The signal source, 2 - Signal receiver, 3 - Acoustic device.

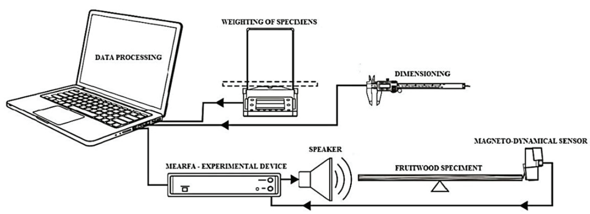

Fig. 5: Scheme of the device MEARFA.

The resonance dynamic device MEARFA method is based on searching of own specimens frequency. Physical - acoustic constant are calculated by fallowing formulas:

Wood density was calculated according to the equation:

$$\rho_w = \frac{m_w}{V_w} \qquad (kg.m^{-3}) \tag{1}$$

where: ρ_w - the density at the given moisture content at the time of measurement (kg·m^{-3}),
m_w - wood mass (kg),
V_w - the wood volume (m^3) at the moisture content w (%)

The dynamic modulus of elasticity along the wood grain of the specimen in the shape of a bar was calculated using the equation:

$$E_L = 4 \cdot l^2 \cdot f_r^2 \cdot \rho, \qquad (Pa) \tag{2}$$

where: l - t he length of the specimen (m),
ρ - the material density (kg.m^{-3}),
f_r - the fundamental resonance frequency in Hz.

Acoustical constant was calculated using the equation:

$$A = \sqrt{\frac{E}{\rho^3}} = \frac{c}{\rho} \qquad (m^4 \cdot kg^{-1} \cdot s^{-1}) \tag{3}$$

where: E - the modulus of elasticity along the wood grain (Pa),
c - the velocity of sound propagation in wood ($m.s^{-1}$),
ρ - the density in ($kg.m^{-3}$).

For calculation of the speed of sound propagation in wood the following equation was used:

$$c = \sqrt{\frac{E}{\rho}} \qquad (m \cdot s^{-1}) \tag{4}$$

where: E - the modulus of elasticity along the wood grain (Pa),
ρ - the density ($kg.m^{-3}$).

Logarithmic dumping decrement (expresses the absorption of acoustic energy by the material) was calculated using:

$$\vartheta = \frac{\pi}{\sqrt{3}} \cdot \frac{f_2 - f_1}{f_r} \tag{5}$$

Where f_1, f_2 are frequencies in Hz, at which the amplitude of the vibrations is half of the maximum amplitude at the resonance frequency f_r.

RESULTS AND DISCUSSION

Results for ultrasonic tester

We show the results of modulus of elasticity and speed of sound propagation in spruce. The results show us the big variations between relations of density and speed propagation.

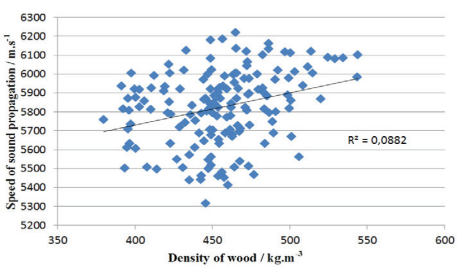

Fig. 6: The relation of the sound velocity and density for spruce.

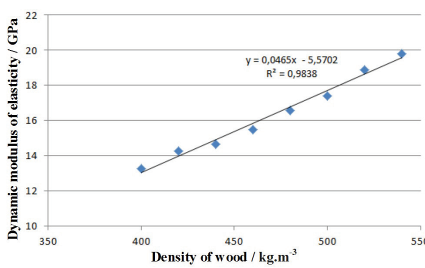

Fig. 7: The relation between the dynamic modulus of elasticity and density for spruce.

The best values reached the density approx. 450$kg \cdot m^{-3}$. The results show that with increasing density of wood acoustic properties, speed of sound propagation and modulus of elasticity increase (Figs. 6, 7).

The modulus of elasticity measured by ultrasonic and with resonance dynamic method are very similar. We have only higher speed of sound propagation. We can say that it is because the resonance spruce showed higher densities of samples.

The results from resonance dynamic method device, MEARFA

We evaluated the results for Siberian larch, larch from Slovakia and resonance spruce also from Slovakian higher latitude areas. We can see in following graphs that sapwood and heartwood for larch are separated and resonance spruce samples were evaluated together because in practise using for instruments making we never separate the sapwood and heartwood of spruce and also the sapwood of spruce is very thin.

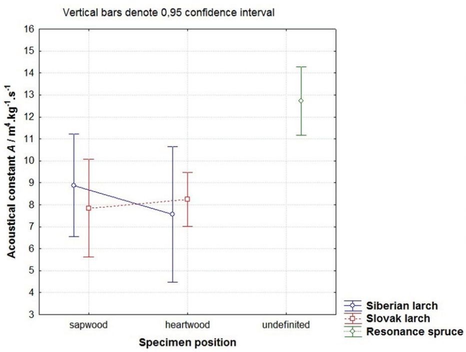

Fig. 8: Acoustical constant for Larch heart wood and sapwood and spruce.

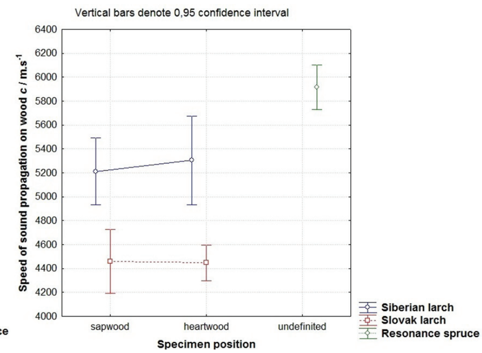

Fig. 9: Speed of sound propagation in larch sapwood, heartwood and spruce.

Acoustical constant is for high quality spruce approx. 12 $m^4 \cdot kg^{-1} \cdot s^{-1}$. We can see that for Siberian larch sapwood it is about 9 $m^4 \cdot kg^{-1} \cdot s^{-1}$. Only few samples reached the value of about 11 $m^4 \cdot kg^{-1} \cdot s^{-1}$. That's mean that we can also find larch with good quality for tops of instruments. Sap wood and heart wood of larch from Slovakia reached the lower values. This species can be used for backs and sides of instruments (Fig. 8).

Speed of sound is highest for the resonance spruce. The lowest is for Slovak larch heartwood and sapwood (Fig. 9). According to some other authors, (Bucur 2006, Danihelová 2004) the speed of sound propagation for spruce for longitudinal direction is approx. 5600 $m \cdot s^{-1}$. Marčok (1988) gives the ratio $c_L : c_R : c_T$ = 15 : 5 : 3.

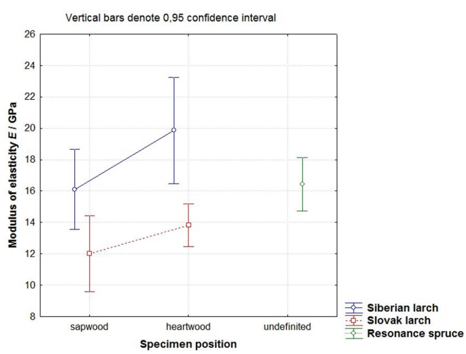

Fig. 10: Modulus of elasticity of larch sapwood, heartwood and spruce.

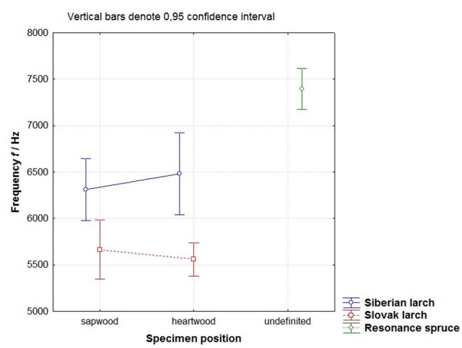

Fig. 11: The resonance frequency of larch sapwood and spruce

The results show that with increasing density of wood acoustic properties, speed of sound propagation and modulus of elasticity increase (Figs. 6, 7). The highest values of modulus of elasticity have samples of Siberian larch. This is the reason why the acoustic constant is not high as for resonance spruce (Fig. 10)

Resonance frequency is very important for device MEARFA because from this value we calculated all physico-acoustic properties of wood. The resonance possibilities of material show us that the best are also the resonance spruce (Fig. 11)

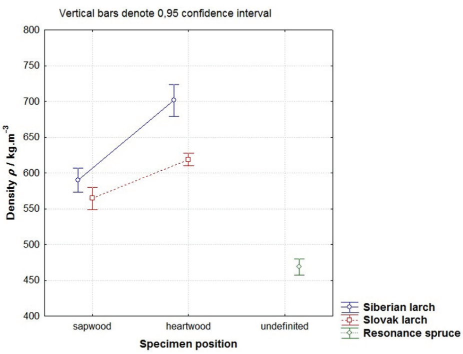

Fig. 12: Comparison of densities for larch sapwood and spruce.

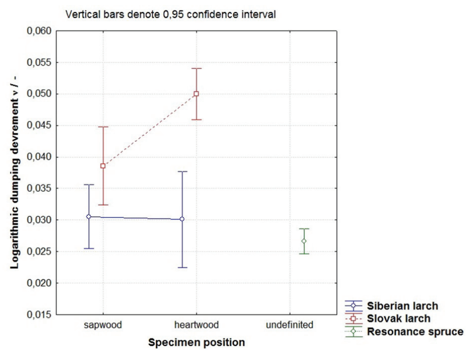

Fig. 13: The logarithmic dumping decrement for larch sapwood, heartwood and spruce.

The resonance spruce have the best ratio of density and acoustic constant with low density we reached very high acoustic constant (Figs. 12, 8).

Ratio of amplitudes is called logarithmic damping decrement. This quantity is a very often omitted property of material. It is a hard question, what influences more this value - the internal friction in material or its radiation possibilities. We know, that the dumping capacities of wood are much higher than other material, this is one of the reasons why wood so unique. We can see low values of logarithmic dumping decrement for resonance spruce and also some samples of Siberian larch reached very similar values (Fig. 13). If we compare the types of measurement, the results are very similar, but we can say that for musical instruments resonance method is better than the device MEARFA. The drawback of this measurement is that it is not possible to measure samples with flat dimensions as with modal analysis using Chladni patterns. The advantage of ultrasonic is a very fast measuring and simple device. Results also show that resonance methods are very sensitive, especially the device with magneto-dynamic sensor. According to some authors (Bucur and Chivers 1991, Mishiro 1996) Haines et al. 1996) the discussions and results on the influence of density on the ultrasonic are not similar. Our results show that with increasing density the sound velocity increases, but for instruments making is very important to find good ratio between density and physico-acoustic properties.

CONCLUSIONS

The results show that spruce is very unique and important material for instruments making, especially chordophones. The acoustic constant shows that it is not easy to change this material for the top of instruments. The Siberian larch from higher latitudes can be also used for top boards of musical instruments, but the end effect of instruments cannot reach the same quality as with spruce of high quality. Also the big problem can occur with the finishing of the surface, because the high amount of resin can influence this process. Larch from Slovakia is not good for instruments making also because it is hard to find material of good quality, this means a good proportion of early and late wood, and also material without knots.

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Pavol Halachan*, Marian Babiak, Dominik Spišiak
Technical University in Zvolen, Faculty of Wood Science and Technology
Department of Wood Science Zvolen
Department of Fire Protection
Masarykova 24
960 53 Zvolen
Slovak Republic
Phone: +421 944 450 602
Corresponding author: pavol.halachan@gmail.com

Anatoly N. Chubinsky, Alexander A. Tambi, Kirill V. Chauzov
Saint Petersburg Forest Technical University
Faculty of Mechanical Wood Technology
Department of Wood Sawing and Drying
Institutskij Per. 5
194021 Saint Petersburg
Russia