

STUDY OF THE WOOD ACOUSTIC PROPERTIES OF THE USING A MODIFIED RESONANT METHOD

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ABSTRACT

Some of the unique properties of the wood are the acoustical. Together with its elastic properties they characterize this material to a great extent. Wood is unique with its characteristic of having high elasticity and damping of the low density.

This work examines the basic acoustic properties, as obtained by resonance method. Specimens of spruce wood, arranged in groups of varying density, are examined. The speed of sound, dynamic modulus of elasticity, acoustic constant and damping are set. Relations between the values of these properties in longitudinal and transverse oscillations are sought. The effect of density on the properties of the wood is established.

Key words: wood, sound velocity, dynamic modulus of elasticity, acoustic constant

1. INTRODUCTION

When musical instruments play, both volume and surface waves spread through them. As the waves propagate at any point in space there are both longitudinal and transverse waves. The relations between them have not been fully explored so far. Wood matter is even more complicated because of its anisotropy. The methods of examination overlap with the nature of the waves, but they can generally be divided into two categories: resonance and ultrasound. Ultrasonic methods are more accurate, but they require expensive equipment and only work with small samples (due to high attenuation).

Resonance methods use samples close in size (especially length) to the dimensions of actual musical instruments. This allows test pieces to be processed in two different ways, thus seeking connection between the acoustic characteristics achieved.

The purpose of this work is to explore the influence of the vibration direction in relation to the fibers direction in the test pieces, on the acoustic properties of spruce wood.

2. METHOD

Test specimens are standard test samples (ST of the CMEA 1143:1978) with cross-sectional dimension 15x15 mm and length 600 mm. Test specimens are selected depending on the width of the annual rings and the density. Annual rings are also selected in a narrow range for each group according to their width and density.

In the first group minimum value of the density is 350 kg.m⁻³, and the maximum – 400 kg.m⁻³. That way the obtained mean value for the density of the first batch, named “low density spruce“ is 380 kg.m⁻³. In the second group of specimens minimum density is 420 kg.m⁻³, and the maximum – 476 kg.m⁻³. Thus, the obtained mean value for the density of the second batch, called "average density spruce" is 450 kg.m⁻³. In the third group of specimens minimum density is 536 kg.m⁻³, and the maximum - 596 kg.m⁻³. The obtained mean value for the density of the third batch (high density spruce) is 560 kg.m⁻³.

The density of the wood sample is determined according to BDS-ISO 3130. The samples are weighed on a technical scale

with 0,01 g resolution, and their dimensions are measured along the axes of symmetry with 0,01 mm. accuracy. Dynamic Young's modulus is defined as:

$$E = 4 \cdot f_0^2 \cdot l^2 \cdot \rho, \text{ GPa} \quad (1)$$

Where: f_0 is the resonant frequency, Hz; l is the length of the wood sample, 600 mm; ρ is the density of the wood, kg/m^3 . Acoustic constant is defined as:

$$A = \sqrt{\frac{E}{\rho^3}} = \frac{v}{\rho}, \text{ kg}^{-1} \cdot \text{s}^{-1} \cdot \text{m}^4 \quad (2)$$

In solids, the speed of sound (v) depends on their density and Young's modulus (Culik, M., et al., 2000):

$$v = \sqrt{\frac{E}{\rho}}, \text{ m/s} \text{ or } v = 2 \cdot l \cdot f_0, \text{ m/s} \quad (3)$$

and damping ratio:

$$\delta = \frac{\pi}{\sqrt{3}} \cdot \frac{f_2 - f_1}{f_0}, \quad (4)$$

Quality factor:

$$Q = \frac{A}{f_2 - f_1}, \quad (5)$$

Where: A is the amplitude; f_1 e f_2 are wave frequency, having half amplitude.

In the determination of the flutter across-fiber the test specimen is placed vertically, snap at its lower end (Fig. 1) and the transducers are arranged in the other end. Source is at the top while the receiver is placed at the site of maximum amplitude. The transmitter, which excites the oscillation (A) is at the end, and the receiver (B) at $l/4$ of that distance („ T ” is the wavelength). Maxima are at $l=T/4$ and $l=5T/4$, and a minimum at $l=3T/4$. Nodes are at $l=0$; $l=T/2$ $l=T$ (Bucur, V. 1995).

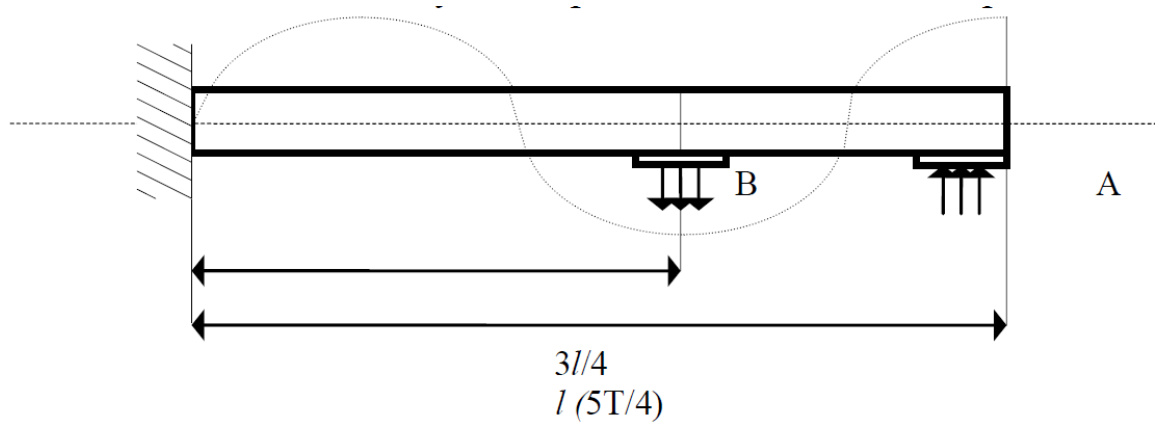


Figure 1: Schematic diagram for determining the velocity of transverse waves in timber

The velocity is determined in two cases, depending on the orientation of the probe body against vibration. Test specimens shall be tested in radial and tangential direction. In this case, the dynamic Yong's modulus is defined as:

$$E = \sqrt{\frac{16 \cdot f_0^2 \cdot l^2 \cdot \rho}{25}}, \text{ GPa} \quad (6)$$

and the speed of sound:

$$v = \frac{4 \cdot l \cdot f_0}{5}, \text{ m/s} \quad (7)$$

Acoustic constant and attenuation are determined by formula, analogous to 2 and 4.

For a better comparison of the individual test pieces' properties, the quality factor is

calculated as well. It is the ratio between the amplitude's magnitude and its damping.

3. RESULTS AND DISCUSSION

3.1. Acoustic parameters in longitudinal oscillations of the fiber

The resulting average value for the resonant frequency of the timber in the first and third batches was about 4400 Hz, while the second batch showed about 4600 Hz (Fig. 2). All three frequencies are at amplitude of about 0,30. First concomitant frequency obtained in the semi amplitude (f_1) of timber vibration, in first and third batches is about 4050 Hz, while in the second - (f_1) – 4700 Hz.

In the second batch, these values were respectively 4400 Hz and 4840 Hz.

Given this, damping of the timber from the first and third batches was about 0,27, while those of the second batch showed 0,17. The value obtained for the sound velocity in timber from the first and third batches was about 5330 m/s, while those of the second batch showed 5570 m/s. The values of the dynamic modulus of elasticity increased respectively from 10,8 GPa to 16,2 GPa from the first to the third batch. Reversely, acoustical constant decreased from 14,0 $\text{kg}^{-1} \cdot \text{m}^4 \cdot \text{s}^{-1}$ to 9,61 $\text{kg}^{-1} \cdot \text{m}^4 \cdot \text{s}^{-1}$. These values are similar to those, found in the literature for spruce wood (Bardarov, N.S., et al. 2000).

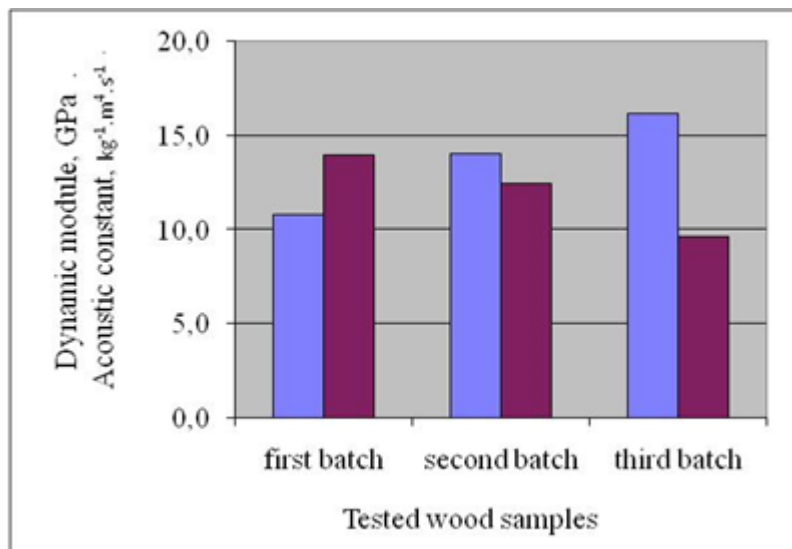


Figure 2: Dynamic modulus (blue bars) and acoustic waves (purple bars) at longitudinal of the fibers

A steady increase of the resonance frequency and thus the speed of sound in relation to increases in density of the wood, was not observed. Highest (if by a little) speed of sound is obtained from the second batch, which has a density of $450 \text{ kg} \cdot \text{m}^{-3}$. The dynamic modulus of elasticity and acoustic

constant both show clear tendency related to increasing density. While Young's modulus increases gradually with increasing density, the acoustic constant on the contrary, decreases. Here as well the averages are relatively high in the second batch.

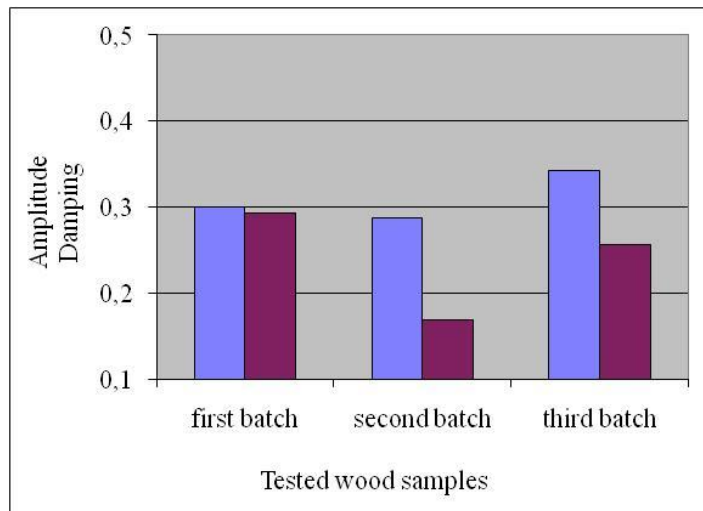


Figure 3: Amplitude (blue bars) and damping (purple bars) in waves along the fiber

The differences between the average values for oscillation amplitude of the longitudinal waves, are little. The highest value of the amplitude has a wood with a high density. The differences in attenuation are bigger, with lowest values in the second batch. As a result, the highest value of the quality factor, a 1,08, is obtained in the timber of low density. Lowest value is obtained from the second batch – 0,70.

3.2. Acoustic parameters in waves through the fibers

The differences in the properties of longitudinal and transverse vibrations of the fibers, are of particular interest. The resonant frequency in the radial direction takes from 40 to 51 % in comparison with the longitudinal. In tangential direction this is from 41 to 59 %.

The speed of sound through the fibers varies from 16 to 24 % of that in longitudinal fiber, depending on density. Dynamic modulus of elasticity in the radial direction varies by 14 to 20 % of that in lengthwise direction.

In tangential direction these figures are 18 to 23 %. The acoustic constant in the transverse direction takes about 0,04 % of the value in the longitudinal direction. As the amplitude of oscillation through the fibers occupies from 33 to 42 % of the values of the longitudinal direction, attenuation in the transverse direction is significantly high. It is increased by 125 to 260 % of that in lengthwise direction.

The obtained average value for the resonant frequency of the transverse waves in the radial direction slightly increased from 1760 Hz for the first batch (at amplitude 0,11) to 2280 Hz for the third (with amplitude 0,136) (Fig. 3).

With the increase in the density, value of the resonant frequency of transverse wave in the radial direction is increased from 843 Hz for the first batch to 1093 Hz for the third. A similar trend is observed in the tangential direction, where it increased from 860 Hz to 1261 Hz.

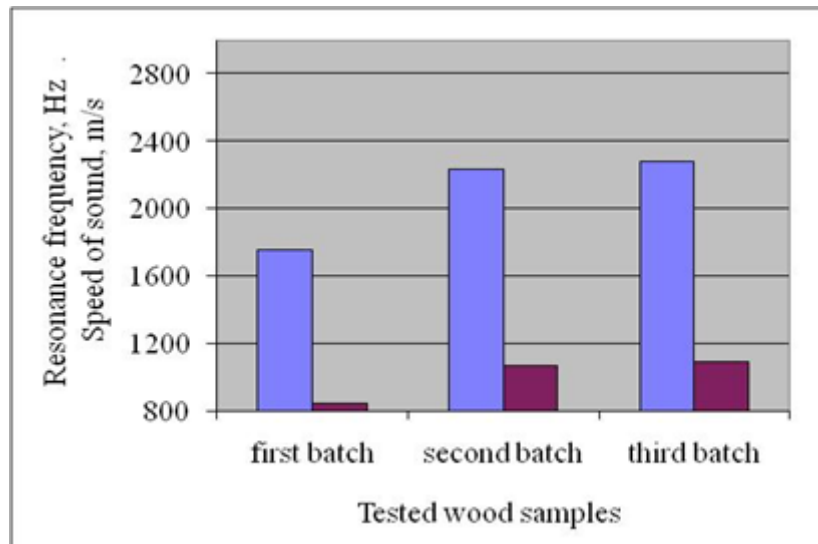


Figure 4: Resonance frequency (blue bars) and the speed of sound (purple bars) in waves across the fibers in the tangential direction

The value of the dynamic modulus of elasticity in the radial direction is lowest in the first batch timber – 1880 Pa, and highest in the second – 2772 Pa. In tangential direction this trend is maintained, as the first batch is 1957 Pa, while the second – 3256 Pa.

The acoustic constants of the transverse wave decreases slightly from $0,01 \text{ kg}^{-1} \cdot \text{m}^4 \cdot \text{s}^{-1}$ to $0,004 \text{ kg}^{-1} \cdot \text{m}^4 \cdot \text{s}^{-1}$. Damping of transverse waves slightly decreased from 0,49 to 0,32, except for the value for the low density timber. Ratio quality factor of transverse waves ranged from 2,9 to 4,7 in the radial direction and from 2,8 to 4,7 tangentially.

There is a slight increase in the resonant frequency of the waves through the fibers – compared with increased density, it gradually grows. This increase was more pronounced through oscillations in the tangential direction. Such tendency is observed in the values for the speed of sound. Likely, the role of the early wood in transverse vibration of the fiber is more significant than that of the late wood, because in low density the speed in both directions is substantially uniform. By increasing the density, differences in radial and tangential direction grow.

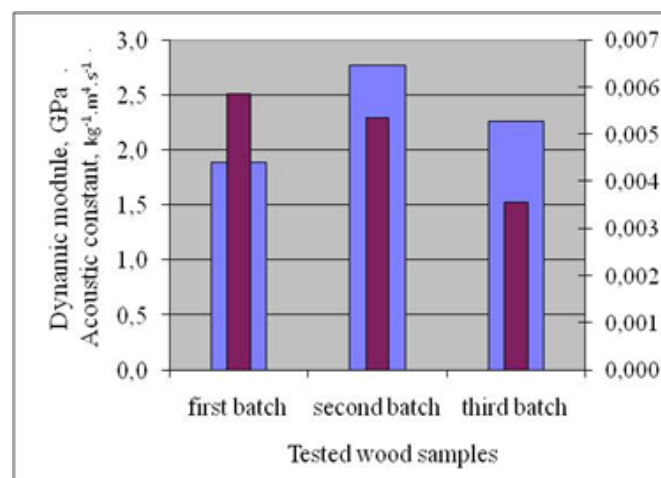


Figure 5: Dynamic modulus of elasticity (blue bars) and the acoustic constant (violet bars) in the fiber cross-waves in the radial direction

Unlike longitudinal oscillations there are no trends here of value distribution, for the dynamic modulus of elasticity depending on the density. In both transverse directions lowest was observed in the timber with low

density. The highest value was observed in samples from the second batch. By further increasing the density, the acoustic constant decreases, more pronounced in the radial direction.

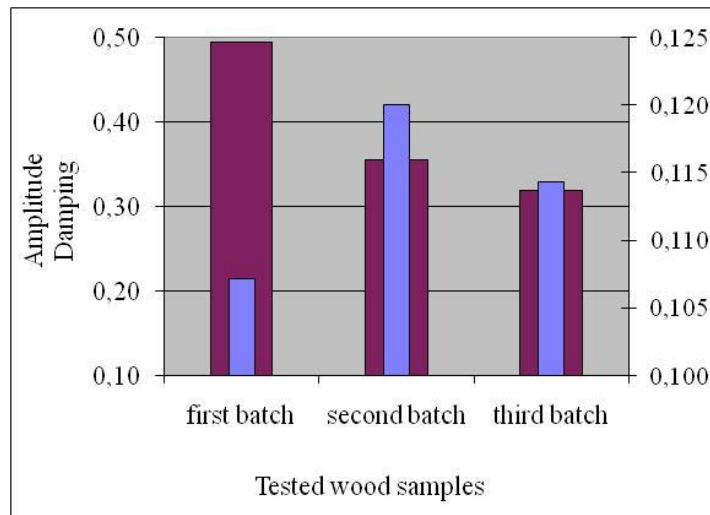


Figure: 6. Amplitude (blue bars) and damping (violet bars) in waves across the fibers in the tangential direction

There was no dependence in the values of the amplitude, related to increase of the density of the wood. In the radial direction, it increases gradually in a range from 0,11 to 0,14. In tangential direction it varies, but in very narrow range from 0,107 to 0,120. There was no dependence observed in the values of attenuation. In the radial direction, it ranges from 0,34 to 0,44, and the lowest value is in the high density timber. In tangential direction it decreases gradually from 0,49 in the first batch to 0,32 in the high density wood.

CONCLUSION

No trend was observed for resonant frequency and the speed of sound in longitudinal oscillations, related to increasing density of the wood. The obtained values are close, the highest are those at $450 \text{ kg}\cdot\text{m}^{-3}$.

In longitudinal oscillation, with increasing density of the wood dynamic modulus of elasticity increases, the acoustic constant gradually decreases. Such relationships were not observed in fiber cross-oscillation.

In transverse direction, the acoustic parameters of the timber with a low density are significantly lower than those in the other two groups, showing similar values in the radial and tangential direction.

In tangential direction the speed of sound is slightly higher than radially.

Ratio of quality factor is significantly less in the longitudinal oscillations, and the lowest density timber batch showed the highest ratio values.

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