Effect of the structure of wood on the results of ultrasound

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Abstract. In article defined the influence of wood density and angle of annual rings on the deviation angle of the ultrasonic (US) signal (beam) by using the through transmission method of sounding wood. For achieving most-reliable control of glued structures, the requirements for the size of transducers were formulated.

1. Introduction

Wood is high plant polymer material having a complex anatomic structure and a big difference between the properties in different directions related to the fiber direction [1-3]. The anisotropy of the wood is a consequence of its heterogeneous structure at both the macro and meso, micro and nanoscale [4-8]. The characteristic elements of microstructure are annual layers forming in cross-section close to the concentric rings of different widths (usually from 1 to 10 mm). Annual layer consists of two parts: the early and late wood whith a different density. The size and density of the annual rings depend on the geo-climatic growing conditions. Such structure of the wood significantly affects the determination of its physical properties. In particular, when through sounding, there is a deviation from the axis of the sound beam sounding (figure 1) [9-10].

![Figure 1](image)

**Figure 1.** Scheme of measurement (a) and the deviation from the axis of the sound beam sounding (b).
As can be seen from the figure, the deviation of ultrasound (US) from the axis of the beam can significantly affect the accuracy of the testing results.

2. Experimental Part

The deviation angle from the axis of the ultrasound sonic investigated on samples of pine wood 156 mm long, 85 mm wide, 26.5 mm thick with a different angle of annual rings, moisture content 12 ± 2%, a surface roughness of 24 ± 8 microns. Environmental conditions: relative humidity of 65 ± 5%, temperature 20 ± 2 °C. For the excitation and reception of ULTRASONIC was used ultrasonic flaw "A-1214 EXPERT". Preliminary studies showed that the high accuracy of the result for the studied samples can be obtained at a frequency of 2.5 MHz. At this frequency minimizes the error related to the loss of the wave, and the ultrasonic attenuation in the material allows you to confidently take passed through the sample signal. The measurements were carried out using 2 piezoelectric transducers PEP 111-2.5-K12.

3. Results and Discussion

The scheme of measurements is shown in figure1a. The radiator (piezo) was placed on one surface of the sample, moving the receiving piezoelectric transducer on the opposite surface reaches a maximum amplitude of the transmitted signal. Figure 1b shows the deviation from the axis of the sound beam sounding: Δx and Δy - displacement transducers relative to each other along two axes x and y, respectively, with the maximum amplitude of the transmitted signal, R - "offset" annual ring, h - the thickness of the sample, F - the angle of the layer, which is calculated as  F = \arctg\left(\frac{R}{h}\right), \delta x - deviation angle with respect to x, \delta y - angle deviation from, \delta xy - the angle of deflection along two axes x and y.

When passing an ultrasonic signal through the sample is observed its displacement, depending on the structure and density of the timber (figure 2). Deviation ultrasonic beam related to the layered structure of the samples formed by the annual rings of different density.

![Figure 2](image-url)

**Figure 2.** Schematic representation of the displacement of the ultrasonic signal, depending on the macrostructure of wood - the location of the annual rings in cross-section and type of sawn timber (radial or tangential): a - radial; b - tangential: A - emitting transducer, B - receiving transducer; F - the angle of the layer.

The deflection angle of the ultrasonic beam along the fibers (axially x) connected with the macrostructure of wood and orientation of the cells caused by the process of tree growth. Figure 3 is a plot of the deflection angle of the signal along the axis of the density of the wood. From figure 3 it is seen that with increasing density of the wood decreases the angle of deflection. However, due to the fact that wood assortments is impossible to predict the behavior of the density, and to predict in which direction (positive or negative) of the axis x will move the ultrasonic beam is not possible. Wood with a low density (less than 450 kg / m³) can not be used for the manufacture of laminated structures and densities of more than 450 kg / m³, the deflection angle of the sound beam constant and less than 0.2 rad.
Deviation of ultrasound signal across the grain (on axis y) due to alternating denser (late) and less dense (early) wood. Figure 4 is a plot of the deflection angle of the ultrasonic signal along the axis y of the density of the wood.

![Figure 3. Dependence of the deflection angle of the ultrasonic signal of the axis on the wood density.](image)

**Figure 3.** Dependence of the deflection angle of the ultrasonic signal of the axis on the wood density.

![Figure 4. The dependence of the deflection angle of the axis y of ultrasonic density of the wood: (a) - for a small (less than 430 kg / m³); (b) - for the mid-range of densities (from 450 kg / m³ to 530 kg / m³); (c) – for a large (greater than 520 kg / m³).](image)

**Figure 4.** The dependence of the deflection angle of the axis y of ultrasonic density of the wood: (a) - for a small (less than 430 kg / m³); (b) - for the mid-range of densities (from 450 kg / m³ to 530 kg / m³); (c) – for a large (greater than 520 kg / m³).
For a small (less than 430 kg / m$^3$) figure 4a and a large (greater than 520 kg / m$^3$) figure 4c density deflection angle ultrasonic signal approximately constant. This is due to a more uniform distribution of density over the sample thickness. For the mid-range of densities (from 450 kg / m$^3$ to 530 kg / m$^3$) figure 4b observed large differences angles of deflection of ultrasonic beam. For samples with a big density contribution to changing the trajectory of the ultrasonic beam makes alternating annual rings.

Figure 5 shows the results of measurement of the deflection angle of the ultrasonic beam depending on the an slope angle of the annual rings for the three density ranges.

It can be seen that for small and large densities (figure 5a and 5b) the angle of annual rings in relation to the edge of timber has no significant effect on the trajectory of ultrasonic beam. For mid-range densities (figure 5b) the angle of deviation of the signal increases linearly with an increase in the angle of annual rings and tangential sections (figure 5b) may reach 0.5 rad.

Dependence of the deflection angle of the ultrasonic beam depending on the slope angle of the annual rings can be described by the following equation:

$$\delta y = 0.56F - 0.0378$$  (1)

Thus, when the thickness of the timber 26 mm ultrasonic beam can be deflected by 20 mm or more, when using transducers with piezoelectric plates of small diameter (less than 20 mm) can greatly affect the results of the control, including no fixation of the transmitted signal.
4. Conclusion
In Europe there is a large number of enterprises producing laminated wood construction for various purposes, including manufacturers of long-span glued structures, orienting its products for the construction of sports stadiums, swimming pools, skating rinks, etc. The decline in the production of inadequate quality control in the construction of factory and consumer products will improve the competitiveness of products.

The relationship between the angle of the growth rings, wood density and deviation of the ultrasonic beam allows ultrasonic methods to assess the structure of the wood and its suitability for further use in the manufacture of laminated structures.

The deviation from the axis of the ultrasound scanning can significantly affect the reliability of the results of US testing of laminated structures, in particular the determination of the coordinates and dimensions of defects of wood (resin pockets and holes from fallen knots, etc.) and wood gluing.

Acknowledgments
The results of the project can be used design and construction organizations to perform operations to determine density of the wood as early fabrication, and during their operation.

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