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METHOD FOR EXPRESS DIAGNOSTICS OF RESONANT PROPERTIES OF WOOD AGED IN BUILDINGS

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New method and technical solutions for nondestructive express diagnostics and targeted selection of spruce wood with unique dendro-acoustic properties aged in buildings are presented. Flow charts of equipment and ways of its application to identify resonant properties of wood in different parts of a building, including the walls made of round timbers, ceiling and floor boards are given. The proposed ways of wood quality diagnostics in buildings has its advantages over conventional methods.

Key words: spruce wood, aged building, GOST for timber test, drilling resistance, radial core, wood macrostructure, e-dendrometer, resonant oscillation frequency, acoustic constant

INTRODUCTION

It is known that after keeping wood in natural environment for a long time it undergoes irreversible processes resulting in a change in its organic composition: lignin fraction increases and the content of hemicellulose fraction, especially pentosane, decreases. Undoubtedly, this process is more extensive in buildings, especially in their ceiling area. Under systematic temperature action, condensation of vapor from "vapor-air" mixture, cooling and reheating soft wood is subjected to mild hydrothermal treatment regime, which is accompanied by heat-mass transfer. As a result, the modulus of elasticity (stiffness) increases and, accordingly, wood resonance properties increase as well.

It is important that seasoned for decades wood in such conditions obtains the stability of physical and mechanical properties including resonance ones. Musical instruments produced from old timber are capable of producing more stable sound spectra even in changing external environment conditions [1]. As a rule, many masters of musical instruments production use not fresh, but kept for at least 15 years or more wood, and some of them have preferred very old wood for that purpose since the old days [2, 3].

However, qualitative wood selection in buildings for this purpose requires new ways of express diagnostics of its resonance properties, since all of the existing methods are suitable only when harvesting wood for raw material for musical instruments production from round or sawn timber as well as from growing trees [4, 5].

MATERIALS AND EXISTING TEST METHODS

The object of studies was an old building where spruce wood strength research was previously conducted [6] (Fig. 1).

The scientific importance of this object lies in the fact that it is situated in the zone of taiga forests of Russia



Figure 1: The object of studies

with a predominance of coniferous species. The main thing here is the fact that scientific expeditions revealed reserves of resonant spruce wood [5].

Requirements to resonant wood are set against visual and technical specifications. The first group of requirements includes: species (mainly spruce, Caucasian fir and Siberian pine (cedar); macrostructure (in many countries the standard for the width of annual rings is no more than 3-6 mm depending on the kind of musical instrument, and late wood content should not exceed 30% (20% for concert pianos sounding boards)) [1]. Simultaneously, strict requirements on normal allowance of flaw in resonance wood are specified.

Determination of macrostructure characteristics is performed on the samples in the form of a prism with the base of 20x20 mm and the length of 20-30 mm along the fibers according to GOST 16483.18 [7].

Preparation of such samples requires laborious time-consuming work: wood cutting, bucking, sawing, etc.

The disadvantages of this method include, firstly, the fact that the research require manufacturing of several adjacent samples according to the set parameters (20 × 20 × 30 mm) on a certain width board, which increases labor costs and, above all, random errors in the measurement of several samples are unavoidable.

Secondly, it is strictly specified that macrostructure determining should be executed on the end plane, which requires additional grinding of this part of the sample as in this case the cross sectional plane roughness parameter Rm_{max} shall be at least 100 μm. In the grinding process, due to the relatively low hardness of the wood material, 'smearing' and less sharp boundaries between early and late zones of the annual ring are inevitable, thereby reducing the accuracy of measurement of these parameters, and, eventually, identification of the resonance timber.

It is known that the main 'musical' indicator characterizing resonance properties of wood is *acoustic sound radiation constant* K which is determined by the following Eq. of Young dynamic modulus of elasticity, E_{dyn} and material density, ρ [8].

$$K = \sqrt{\frac{E_{dyn}}{\rho^3}} \tag{1}$$

Note: for sounding wood the threshold value is $K \geq 12 \text{ m}^4/\text{kg}\cdot\text{cm}$

To determine the density of timber GOST 16483.1 [9] is enacted, which provides for the manufacture of standard samples in the form of a rectangular prism with 20 × 20 mm base and 30 mm length along the grain.

Young dynamic modulus of elasticity, E_{dyn} , can be determined by several methods, ultrasound one being one of them, by calculating it by Eq.

$$E_{dyn} = C^2 \times \rho \tag{2}$$

where C is sound propagation velocity in wood, m/s.

A more precise definition of E_{dyn} is against the resonant frequency of forced longitudinal oscillation of the sample

$$C = 2lf_0 \tag{3}$$

where l is the length of the sample, m

f_0 is resonant frequency, Hz.

Special Standard 16483.31 [10] also exists to determine this parameter which provides for the production of standard 20 × 20 × 300 mm bars.

Consequently, the standard methods presented do not allow to determine the resonant and other physical and mechanical properties of wood either in timber sets or roof and floor boards in an expeditious manner without removal of buildings. In addition, receiving these parameters requires a specialized laboratory equipped with a rather complicated equipment.

During the analysis of modern techniques in the diagnostics of the resonant properties of wood in buildings several methods and technical solutions were identified

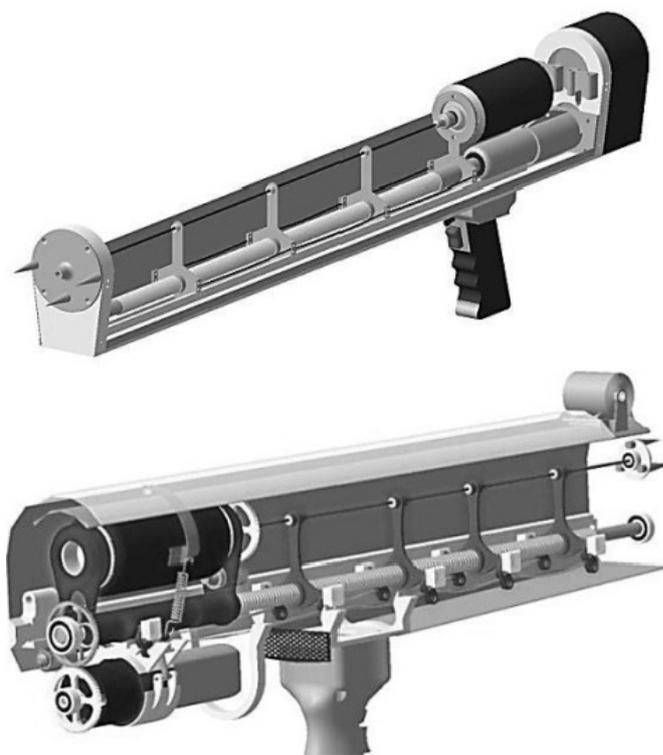


Figure 2: Device for measuring drilling resistance

which are presented below.

Using the device for measuring drilling resistance (Fig.2) can be considered a modern method for determining the physical and mechanical characteristics of growing trees, lumber and wooden structures [11]. The method consists in determining power parameters of drilling wood with a thin boring bit with a constant feed force. The power expended on drilling and feeding correlates well with wood density and its macro structural parameters. A boring bit diameter is 3 mm, which is much smaller than diameters of standard borers. Therefore, it belongs to quasi-non-destructive methods of express diagnostics of wood.

The disadvantage of the method and device is that the actuator of a device is a conventional one-piece boring bit and thus no sample is taken from the wood, without which it is almost impossible to determine the color of the wood as an important indicator of the quality of resonant material.

Therefore, without taking a test piece it is difficult to carry out full quality diagnostics and targeted selection of resonant wood in a building.

Electronic microdendrometer [12] can also be used for diagnosing resonant properties of standing tree wood. This method is carried out by determining in vitro the dynamics of annual rings width changes and content of late wood in radial transverse cores taken from a growing tree with age auger.

The disadvantage of this method and device can be attributed to the fact that to carry out further research it is necessary to deliver the taken sample to a specialized laboratory, which will require additional effort and time.

Therefore, such method limits the possibility of carrying out full express diagnostics and target material selection at the old wooden building itself. The main thing is that during the time of test sample delivery to the laboratory a change of its original moisture content due to the desorption of wood takes place. It affects the dynamics of physical and mechanical properties and therefore reduces the accuracy of their evaluation.

The forest industry has developed a new method for express diagnostics of resonant properties of standing wood [13]. To implement it, electrical increment borer is used. This device is attached in a certain way to the caliper which grabs a tree at three points and thus allows to direct the borer working body strictly according to the radius of a trunk and remove radial across-the-grain cores and simultaneously carry out physical and mechanical measurements in this significant for resonant material direction.

This method has the disadvantage for the diagnostics of wood in buildings as well, because logs are located tightly to each other, and a certain part of their surface is generally cut off when building a log house. This is why it is difficult to direct the borer strictly in the radial direction of a log. This entails a distortion of the results of all the measurements, because wood is not an isotropic but an orthotropic body whose physical and mechanical properties differ along three main axes of wood anisotropy.

The analysis of developments in the field of wood diagnostics showed that existing methods and devices are quite laborious and do not allow to obtain full range of parameters necessary to determine resonant properties of wood in old buildings.

RESULTS AND DISCUSSION

Diagnostics of wood resonant properties in the wall part of a building

To avoid the above mentioned disadvantages we propose a new method for express diagnostics of resonant properties of wood aged in old structures [14] which is based on modernization of the known device [13].

The process is carried out as follows (Fig. 3). Using a compass, reconnaissance of the building is done and location of the walls relative to the cardinal points and prevailing wind rose is identified. Appropriate notations are put on timber sets against the cardinal points. The priority is the wall located on the south side of the building and maximally perpendicular to the prevailing wind rose. The wood there is more exposed to light and temperature-and-humidity factors compared with other sides. These factors contribute to more intense degradation of wood hemicellulose fraction, thereby increasing the specific lignin content and, accordingly, the modulus of elasticity. The information about the wind rose in the region is taken from the meteorological directory.

At two opposite ends of a timber set, using a carpenter's level, strictly horizontal lines are drawn going through the

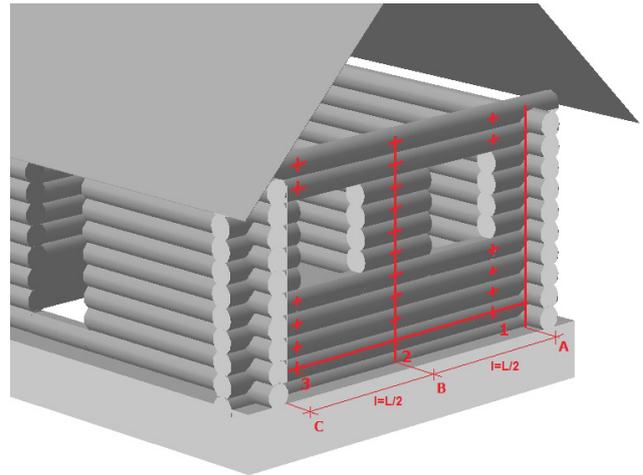


Figure 3: Markup scheme of the areas for express diagnostics of wood

diagonals. Subsequently $200 \times 200 \times 500$ mm bars are attached to both ends on these lines (pos. 1, Fig. 4) so that their ends exposed for at least 200-300 mm from the ends of the perpendicular timber set. Between the two attached wood strips two ropes are tensioned (pos. 2, Fig. 4) which further act as a guide forwarding the borer strictly in a diagonal direction of the timber set under study.

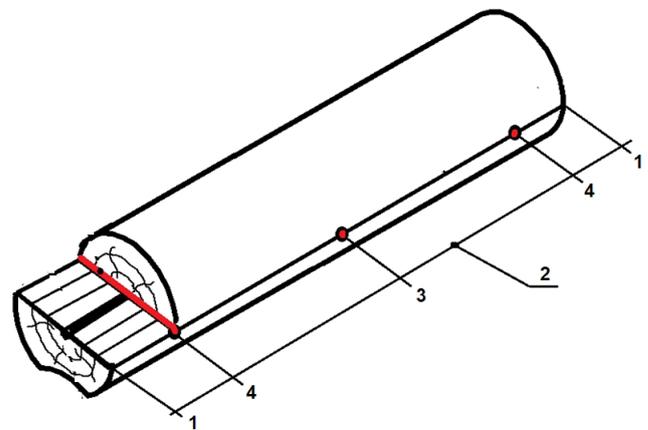


Figure 4: Markup scheme of the areas for express diagnostics of wood on any given structural element of the building

Using these ropes as reference, three points are marked on the timber set: in the middle (pos. 3, Fig. 4) and on the sides, moving away from the cup (log house) for 500-600 mm (pos. 4, Fig. 4). From these places radially transverse cores of 4.0 mm in diameter are taken with a drilling device [14] to evaluate wood color. Wood species, its macrostructure, density and dynamic modulus of elasticity are evaluated against the dynamics of drilling resistance. Further matching of these parameters with standard criteria [1, 5] automatically, i.e. in real time mode, allows the object under study to be defined as resonant raw material.

Diagnostics of wood resonant properties in the ceiling and floor boards of a building

This work is carried out in stages, identifying the compliance with the requirements to resonant material by macrostructure and dendro-acoustic parameters.

At the first stage, by visual examination of the macrostructure (Fig. 5) and presence of flaws in wood, the boards of softwood are marked having strictly radial cutting that do not contain flaws of wood restricting its use as resonant material.

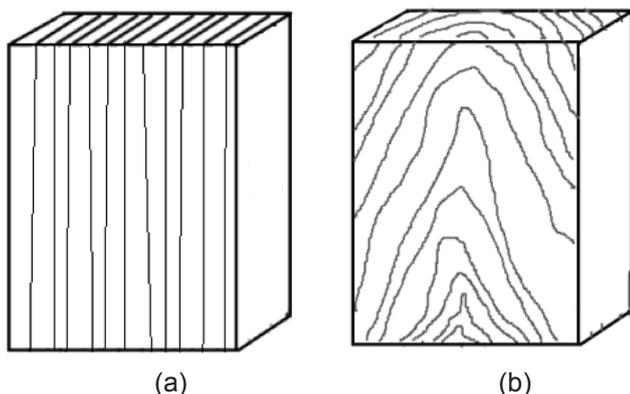


Figure 5: Wood texture of sawn face: a) radial cutting; b) tangential cutting

Further on, specimens in the form of 500 ... 600 mm long rectangular plates are cut out from the middle part of the board to approximately the middle of the sawn face strictly perpendicular to its rib using, e.g., a jigsaw.

To study wood macrostructure, the sample in the form of a cuboid of about 25 ... 30 mm in width is cut off the end of each board, and the rest is left for dendro-acoustic research.

Evaluation of wood macrostructure in this sample can be performed in the vicinity of an object using new devices created at the Volga State University of Technology - electronic dendrometer and microdendrometer. The principle of operation is described in some papers [5, 12, 15, 16]. Using these devices allows to identify not only the dynamics of annual rings width and the content of late wood in them, but no less important feature of resonant wood structure which is the dimension of the width of 'transition zone' from early to late wood within an annual ring [17].

It should be noted that an important role of the transition zone in forming acoustic properties of resonant wood is also proved by foreign scientists [18].

The rest of the sample can be used to carry out dendro-acoustic studies using new technical facilities as well. For this purpose, a special device which action is based on the principle of acoustic feedback can be applied [5, 16]. It identifies:

1. sound velocity in longitudinal direction, C , m/s:

$$C = \frac{0,983 l^2 \cdot f_{res}}{h} \quad (4)$$

2. Young dynamic modulus of elasticity, E , H/m²:

$$E_{dyn} = 0,965 \frac{l^4}{h^2} f_{res}^2 \rho \quad (5)$$

value of acoustic constant of a sample, K , m⁴·kg⁻¹·cm⁻¹:

$$K = \frac{0,983 \cdot l^2 \cdot f_{res}}{\rho \cdot h} \quad (6)$$

where f_{res} is eigen (resonant) frequency of samples, Hz;

l , h are the length and thickness of samples, accordingly, m;

ρ is material density, kg/m³.

In the cases when the thickness of ceiling or floor boards is 400 mm or more, express diagnostics of resonant properties can also be carried out with a drilling device. Doing this, the auger is directed perpendicularly to the lateral face approximately in the middle of the board attached by a conventional pressing device such as vise.

CONCLUSIONS

Thus, there is real possibility for express diagnostics of resonant properties of wood directly in old structures.

The above methods and technical facilities can be used in non-destructive quality material selection for manufacturing and other special purpose assortments with predictable wood specifications.

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