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DEPENDENCE OF SPRUCE WOOD RESONANCE PROPERTIES ON ITS CHEMICAL COMPOSITION

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ABSTRACT

Nowadays there are no reasoned scientific data on inter relation of resonant properties of spruce-tree wood and its chemical composition. Thus the purpose of the study was to reveal the features of sonorous spruce in view of the content of basic organic substances in their timber.

20 model trees at the age of 180-190 years were selected as material for studies in taiga woods in the north of Kirov region of Russia. Special 0.5 m long blocks were made from each model tree at height of 1.3 m. Standard 20×20×300 mm samples were made from those blocks. Test samples were kept at room dry conditions for 2 years. After that dendro acoustic studies were carried out on them to define acoustic constant in different directions with respect to timber fibers. Further the percentage of cellulose, lignin, extractives and ashes in them was defined applying standard techniques.

As a whole the chemical composition of spruce tree resonant wood lies approximately within the same limits as in common wood of the breed given. However significant influence of cellulose on a longitudinal acoustic constant and lignin on a radial constant is revealed. Joint influence of lignin and cellulose on a tangential constant is found out, the influence of lignin in the latter case being dominant.

Continuation of fundamental research in this field has great cognitive value for revealing the nature of unique acoustic properties formation in sonorous spruce wood. Such studies acquire special topicality when dealing with outstanding violins as well as the wood kept for many decades in old buildings subject to demolition.

KEYWORDS: Sonorous spruce, wood density, acoustic constant, cellulose, lignin, extractives, ashes.

INTRODUCTION

It is known, that different species of wood do not differ in the content of basic chemical elements, including carbon, oxygen, hydrogen and nitrogen. In aggregate they form an organic part of wood (cellulose, hemicellulose, and lignin) and a group of extractives (thus, gum, fats, and tannins). Organic substances constitute no less than 99% of total mass of wood. The rest is represented by mineral substances which form ashes after wood burning (Ugolev 2001).

Unlike element chemical composition, relative content of organic substances in wood of one species does not remain unchangeable. Beside the species its influenced by a certain part of a trunk or other parts of a tree taken, age and growth conditions. For example, in the environment of Latvia, the content of cellulose in spruce wood is established to decrease progressively as soil conditions deteriorate, namely, 52.1% in III class bonitet (according to Orlov's scale) and 48.5% in IV. Class bonitet forest stands. Similar phenomenon is revealed for pine woods as well (Kalnynsh 1949).

Therefore, finding out the correlation of wood acoustic properties and its organic structure has both cognitive and practical value. In this connection great many of research and experiments are devoted to studying the role of thus (oleo resin). Thus is proved to play a negative role in resonant wood products. Firstly, with the increase of thus content, sound characteristics and acoustic constant decrease despite of small reduction of Young's modulus of elasticity (Huber 1989). Secondly, filling wood micro- and macrostructures with thus proportionally reduces its air-and-sound permeability, thus raising internal-friction coefficient (Aturina 1937, Fedyukov et al. 2016, Fedyukov et al. 2015). All this has rather an adverse effect on 'useful acoustic effect' of the material and, hence, the musical instrument itself (Ille 1979). Its hould also be mentioned that masters of manufacturing musical instruments mark the difficulty of processing wood with increased content of thus.

Therefore, thus content amount in wood is one of the basic diagnostic attributes for selection of resonant forest product. This is confirmed by the fact that sonorous spruce from Šumava (Czech Republic) having small content of resinous substances has been used for producing violins for many centuries (Vitachek 1964).

Some distinctions in relative content of organic substances in the wood of ancient musical instruments, including violins, are also marked. They are stated to have higher content of lignin and lower content of hemicellulose (pentosans and hexosans) in comparison with fresh wood. Such distinctions are explained by the action of time on wood and not by its initial quality (Holz 1981, Kollman 1983).

Chemical analysis of ashes from the wood of old unique violins showed that mineral content of calcium and magnesium in them was 1.28-1.60%, while in the wood of modern musical instruments it amounts to 0.18-0.45%. It has been proved that such distinction in chemical composition of wood is not connected to its natural primary quality, and grows out of collateral actions of special long storage and floating logs downstream mountain rivers which water contains a substantial amount of these elements (Bariska 1978, Devide 1989).

We failed to find in literature data on special research directed at establishing straight-linecorrelation between natural chemical composition of wood and its acoustic parameters.

MATERIALS AND METHODS

Test samples were selected during special expeditions to Maysky timber enterprise of the Kirov region. This region is included into a zone of taiga woods and is basically represented by spruce groves.

Study samples were prepared on two experimental forest sites with approximately identical structure of forest stands with 8 spruce-trees, 2 fir-trees and a single birch (8S2Fsing.B). However those sites differed in forest growth conditions and productivity of forest stands.

The first site (A) was in a bilberry-spruce grove; the stand was of III class bonitet. The second site (B) was located on an elevation in a wood sorrel spruce forest where the forest stand was of more productive II class bonitet.

Ten model trees were cut down on each experimental forest site. Those were 180-190 year old trees. Certain 0.5 m long round logs were made from each model tree at breast height 1.3 m. This part of the work was executed according to GOST 16483.6. The given standard fully complies with ISO4471-82.

Standard samples of 20×20×300 mm (the long side goes along fibers) were made of these round logs according to GOST 16483.21. The general order of obtaining test samples is presented in Fig. 1.

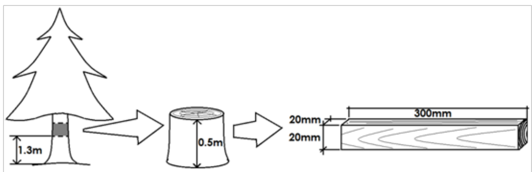

Fig. 1: The order of research material selection and samples manufacturing.

Test samples were kept in dry conditions for 2 years. After that dendro acoustic research was done on them to define moisture content (GOST 16483.7-71), density (GOST 16483.1-84), and ultrasound velocity along and across fibers. The general principle of taking similar measurements is described in our work published earlier (Fedyukov et al. 2016).

On the basis of the research results the Young's modulus and acoustic constants in both directions were determined (Bucur 2006, Fedyukov et al. 2015). *C* sound propagation speed in timber was measured with UK-14 P pulse ultrasound device through measuring τ time of longitudinal elastic wave propagation along l sample length:

$$C = l/\tau \tag{1}$$

It is important to note, that there was a 60 Hz piezoelectric transducer used in the device, which is most appropriate for timber study.

Sound propagation speed in the material and its density given, it is possible to define E Young's dynamic modulus of elasticity, considering the following:

$$C = \sqrt{\frac{E_{dyn}}{\rho}}, \quad \text{then} \quad E_{dyn} = C^2 \cdot \rho. \tag{2}$$

It is well known that the value of *K* sound propagation constant suggested by Andreyev (1938) is taken as a main criterion of material musicality in many countries.

$$K = \sqrt{\frac{E}{\rho^3}} \tag{3}$$

Note: $K \geq 12$ $m^4 \cdot kg \cdot cm$ is a threshold value for sonorous wood.

150 samples were subjected to chemical analysis. They had *K* acoustic constant within the limits of 10.9-14.7 $m^4 \cdot kg \cdot cm$. However, after mathematical analysis by the criteria of 'gross

blunders', further statistical and correlation processing was made on the basis of a smaller number of samples both in general and from separate sites A and B (Tab. 1).

Chemical properties of wood were studied by defining relative content of CP (percentage of cellulose), LP (percentage of lignin), EP (percentage of extractives) and AP (percentage of ashes) in it. Chemical analyses with this purpose were carried out according to the following techniques:

- the content of cellulose was defined by Kürschner-Hoffer's nitric-spirit method;
- the amount of lignin in samples was defined by Komarov's technique;
- extractive substances (thus and fats) were extracted with spirit-benzol mixture;
- the content of thus was defined by burning the wood with subsequent calcination of the residues in muffle furnace at about 6000°C for 3-4 hours; after cooling up to room temperature the substance was weighed;
- the content of ashes was defined in percentage to the weight of absolutely dry wood.

In chemical analyses, when extracting cellulose and lignin, und terminable loss can amount to 2 ¬% for each component. Therefore we calculate relative parameters using the formulas:

$$CP = CP/CP+ LP + EP + AP \times 100\% \quad (4)$$

$$LP = LP/CP+ LP + EP + AP \times 100\% \quad (5)$$

RESULTSANDDISCUSSION

The results of the studies on chemical composition, density and acoustic constant in the directions of spruce wood anisotropy are presented in Tab.1.

Tab. 1:Average values of chemical composition of spruce wood with various acoustic constants and density on sites A and B.

Parameter	Number of samples		Mean value X ± m	
	A	B	A	B
Basic density (kg·m^{-3})	43	94	354.40±3.36	358.12±3.14
Cellulose (%)	»	94	63.16±0.24	62.89±0.16
Lignin (%)	»	96	33.44±0.10	33.47±0.10
Extractives (%)	»	95	2.50±0.12	2.900.41
Ashes (%)	»	97	0.21±0.01	0.20±0.01
Longitudinal acoustic constant (m^4/kg•cm)	»	96	12.39±0.15	12.43±0.12
Radial acoustic constant				
(m^4/kg•cm)	»	97	4.75±0.08	4.56±0.06
Tangential acoustic constant, (m^4/kg•cm)	»	96	3.49±0.05	3.43±0.03

The research results presented in Tab. 1 testify that, basically, chemical composition of spruce wood is approximately the same as with common wood of the given species, irrespective of the value of acoustic constant.

The only exception is cellulose. It is a bit higher content in sonorous wood of spruce-trees in comparison with common wood is quite explainable. Cellulose is the main component of cellular walls of plants causing mechanical durability and elasticity of plant tissues. In the case under consideration some samples with higher acoustic constants (K ≥ 12 m^4/kg·cm) had 70-72 % of cellulose.

On the average, its content amounted to 63.16 % the trees on A site and to 62.89 % on B site (common wood of this species contains cellulose within the limits of 50-58%. Fluctuations of parameters are connected with methods of extracting the given component from wood (Ugolev 2001).

Meanwhile, there was no significant difference in the content of cellulose in the trees on sites A and B. If the research results are analyzed with Student's test, the divergence is obviously not essential (t <3). This is also true for the content of extractives.

Consider a degree of correlation of acoustic constants with these components of chemical composition, using both groups of trees from separate sites, and the data for two sites on the average (Tab. 2- 4).

Tab. 2: Coefficients of correlation of acoustic constants with the components of spruce wood composition (Site A).

Components	Coefficient of correlation (r) with acoustic constants		
	K_L	K_r	K_t
Cellulose, CP	0.397	-0.261	-0.057
Lignin, LP	-0.378	0.269	0.103
Extractives, EP	-0.096	0.185	0.073
Ashes, AP	-0.215	0.295	0.015

Positive correlation of K_L longitudinal constant with the percentage of cellulose in wood and radial constant K_r with the percentage of lignin is the most valuable information given in Tab. 2. Tangential constant K_t has positive correlation with relative content of lignin as well; however reliability of this correlation is less than 50%.

Attention should also be paid here to rather high negative correlation of K_L longitudinal constant with the percentage of lignin r =-0.378. The same correlation is admitted between radial constant K_r and cellulose r =-0.261. Negative correlation of tangential constant K_t with the same component r =-0.047 is very low, i.e. close to zero.

The results specify the greatest influence of cellulose on a longitudinal constant, of lignin on a radial constant and mutual influence of lignin and cellulose on a tangential constant. Nevertheless the influence of lignin in the latter case prevails.

Negative correlation of a longitudinal constant with lignin can be explained by the fact that this organic substance plays basically the role of 'filler' in wood structure, which influences its density directly. As with the increase of material density its acoustic constant decreases, increase in the content of lignin in wood results in longitudinal constant decrease.

The role of cellulose and lignin in view of the parameters of cross-section constants is less evident than of those of a longitudinal one, being less significant in a tangential than in a radial direction.

Correlation coefficients of acoustic constants and the content of extractives and ashes are unstable in view of size. However the radial constant and the content of extractives showed a steady positive correlation. Correlation coefficients of longitudinal and tangential constants with extractives are close to zero; besides, no constant has a steady correlation with the percentage of ashes.

On B site, in a more numerous group of trees, only correlation of a longitudinal constant with the percentage of cellulose proved to be true (Tab. 3).

Tab. 3: Correlation coefficients of acoustic constants with the components of spruce wood composition (Site B).

Components	Correlation coefficient (r) with acoustic constants		
	K_L	K_r	K_t
Cellulose, CP	0.150	-0.242	-0.021
Lignin, LP	-0.309	-0.100	-0.031
Extractives, EP	0.082	0.248	0.028
Ashes, AP	0.166	0.085	0.102

The value of positive correlation coefficient of a longitudinal constant and the content of cellulose in group B compared to group A decreased more than twice (from 0.397 to 0.150). However the value of correlation reliability amounted approximately to 85%.

Tab. 4: Coefficients of correlation of acoustic constants with the components of spruce wood composition (overall results forthe object).

Components	Correlation coefficient (r) withacoustic constants		
	K_L	K_r	K_t
Cellulose, CP	0.216	-0.230	-0.024
Lignin, LP	-0.320	-0.025	0.002
Extractives, EP	-0.028	0.223	0.015
Ashes,AP	0.093	0.019	0.041

The generalized results on both sites, i.e. average parameters on the object as a whole, confirm with insignificant exceptions the regularity of the correlations established (Tab. 4).

CONCLUSIONS

On the basis of the research results stated it is possible to conclude the following:

- spruce-tree sonorous wood differs from conventional one in rather high content of cellulose;
- spruce-tree sonorous wood with various acoustic constants does not differ from conventional wood of the species under consideration in the content of lignin, extractives (thus and fats) and ashes;
- no essential distinctions were found out both for the components specified and in their correlation with acoustic constants of spruce wood formed on different sites, namely, in bilberry-spruce groves and wood sorrel spruce forests;
- the reexists positive correlation between a longitudinal acoustic constant and the content of cellulose;
- the correlation is negative and unstable between cross-section acoustic constants and the percentage of cellulose, and it is unstable and insignificant as for the percentage of lignin is concerned;
- no significant correlation was found between the acoustic constants and relative content of extractives and ashes in wood.

Thus, despite the positive correlation present, especially between a longitudinal acoustic constant and the content of cellulose, the correlation is insignificant. Therefore it is impossible to predict resonant properties of newly felled spruce-tree wood according to its chemical composition. This technique is also unsuitable for instant diagnostics and target selection of material for manufacturing musical instruments.

However continuation of basic research in this field is of great value for understanding the nature of formation of unique acoustic properties of this common, at first sight, natural material. Similar research of wood properties of distinguished violins as well as old wooden structures considered not repairable and subjected to demolition is becoming especially relevant.

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