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DIFFERENT WAYS OF ELASTIC MODULUS COMPARATIVE STUDY TO PREDICT RESONANT PROPERTIES OF STANDING SPRUCE WOOD

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ABSTRACT

Resonant method of determining modulus of elasticity and shift and decrement of fluctuations' operates in Russia to determine elastic-viscous properties of wood (GOST 16483.31-197474). The method is destroying and demanding much time and expenses for manufacturing pre-production models in the form of rectangular bar sized 20×20×300 mm, which requires tree cutting down, severing, sawing, etc.; as a consequence, it has not found wide implementation in the practice of research and, especially, selection of qualitative material for musical instruments manufacturing.

The work objective is to conduct basic research on revealing a more effective and precise non-destructive method for identifying Young's dynamic modulus of elasticity as a basic criterion of standing spruce-tree resonant wood quality with the aim of its selection at an early age and creation of perspective object for woodworking with reference to musical instruments manufacture.

KEY WORDS: Modulus of elasticity of wood, sound speed in wood, resonance frequency, young spruce wood acoustical constant, sonorous spruce

INTRODUCTION

Physical essence of resonant wood due to its macro- and microstructure (Blskova and Brdarov 2003, Fabisiak 2005, Fedyukov et al. 2016) represents 'a combination of incongruous properties'; it should be light and rigid, simultaneously, i.e. have high modulus of elasticity.

To determine the modulus of elasticity they use measurements of elastic deformations under static tests of material or various dynamic methods; accordingly, they distinguish static and dynamic modulus of elasticity, and the classification of methods of their determination can be presented as follows (Fig. 1):

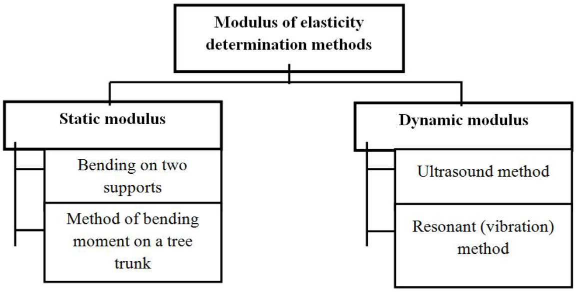


Fig. 1: Methods for determining modulus of elasticity.

Static methods of the modulus of elasticity determination do not represent practical interest for non-destructive diagnostics of standing wood resonant properties. A small exception here is the method of bending moment on a tree trunk 10-25 cm in diameter applied with lever fixture gravity of a person with subsequent assessment of the trunk bouge (Aoki and Yamada 1972).

The drawback of the method given, beside the fact that it is labor consuming, complex and low productive, is its applicability only for trees with trunks 10-25 cm in diameter, whereas for understory early diagnostics the optimum thickness of trunks is 3-5 mm. The point is that this method makes it possible to reveal only static wood modulus of elasticity, whereas for diagnostics of resonant properties the information on the dynamic modulus is required.

In recent years wood science has gathered considerable theoretical and practical experience on determining this parameter, and the methods applied develop in two directions: ultrasonic and resonant-vibrating, both methods being implemented in the practice of resonant wood selection not only to assortments (Ugolev 2001), but to standing wood as well (Bucur 2006, Fedyukov 2016).

In this regard, the necessity of comparative research on revealing the efficiency of its results implementation and, the main thing, accuracy of measurements achievable seems quite reasonable and urgent.

MATERIALS AND METHODS

For the material of test samples for dendroacoustic studies, cuttings were taken from lateral branches of the crone central part strictly from the southern side of 12 young spruce trees in the age of 23-25, 3,0...7,0 mm in diameter and 70,0...100,0 mm in length.

Dendroacoustic research was carried out after keeping the samples till they obtain ambient-dry value of moisture content, i.e. 8± 2 % and was controlled with a hydrometer.

Ultrasonic research was conducted with the help of УК-14П device through measuring the time of elastic longitudinal wave distribution along the sample and determining sound speed according to Eq. 1:

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

where: C - sound propagation speed ($m \cdot s^{-1}$),

l - sample length (m),

t - time of longitudinal elastic wave propagation (s).

The sound speed in wood and its density given, it is possible to determine dynamic modulus of elasticity according to Eq. 2:

$$C = \sqrt{\frac{E_{dyn}}{\rho}}, \qquad \text{TO} \qquad E_{dyn} = C^2 \cdot \rho, \tag{2}$$

where: E_{dyn} - dynamic modulus of elasticity (MPa),
ρ - density(kg·m^{-3}).

Density was determined by a known stereometric method.

The general order of complex research is given in Fig. 2.

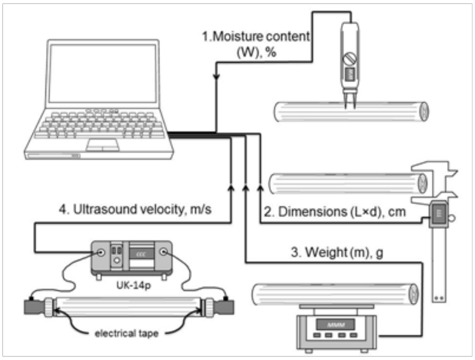
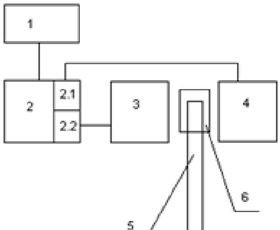


Fig. 2: Principle diagram of experimental measurements.

It is important to note, that the device used a piezoelectric transducer with 60 kHz frequency, which is optimal for wood studies.

Vibro-acoustic research was carried out on the same 12 samples after ultrasonic tests. For this purpose a special hardware-software complex was used, its principle diagram is presented in Fig 3.



1 – monitor; 2 – computer, containing: 2.1 – sound board input, 2.2 – sound board output; 3 – TK-67-H-type vibrator; 4 – TK67-H-type transducer; 5 – sample; 6 – ferromagnetic 'cap'

Fig. 3: Principle diagram of hardware-software complex for defining frequency-amplitude properties of wood.

The hardware-software complex represents a system consisting of an electromagnetic vibrator (3), stimulating vibrations of the sample under testing (5) with the help of a 'cap' (6) made of ferromagnetic material and an electromagnetic transducer (4), recording amplitude and frequency of vibrations of a sample. A harmonious signal from the sound board output (2.2) is forwarded to the vibrator through the connecting cable (3). The signal from the transducer (4) reaches the sound board input (2.1) and automated data processing is carried out, the corresponding amplitude-frequency characteristics appearing on the screen of the monitor (1) allow to define the sample proper (resonant) frequency against the maximal amplitude (Fig. 4).

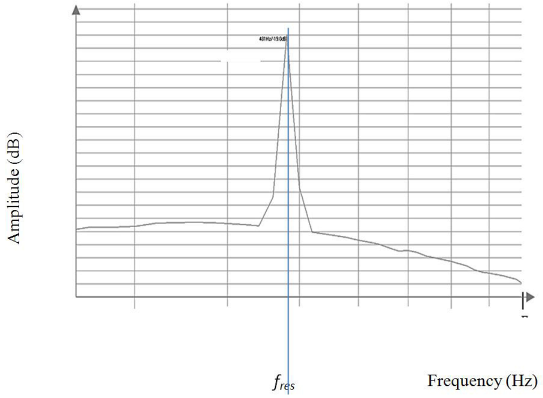


Fig. 4: Wood proper (resonant) frequency assessment.

To create an electromagnetic field and excite vibrations of a wood sample, a cap representing a cylinder made of 'soft' ferromagnetic material is set on its free end, allowing to change the diameter depending on the size of a sample.

Specifications of the complex:
- range of working frequencies is 20 Hz – 1.5 kHz;
- active resistance of the vibrator is 50 Ohm;
- active resistance of the transducer is 50 Ohm.

The basic part of the hardware-software complex is the device with console fastening of a sample tested (Fig. 5.).

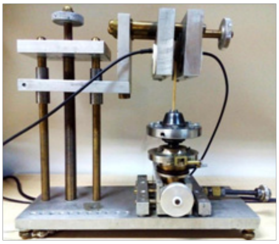


Fig. 5: General view of the device with console fastening of a sample.

Dynamic modulus of elasticity is calculated using a hardware-software complex in an automatic mode according to the following Eq. 3:

$$E_{dyn} = 12{,}775\,\frac{l^4 f^2 \rho}{r^2}, \tag{3}$$

where: E_{dyn} - Young's dynamic modulus of elasticity (MPa),
l - length of the sample (m),
f - proper (resonant) frequency of the sample (Hz),
ρ - density of the sample (kg·m^{-3}),
r - radius of the sample (m).

RESULTS AND DISCUSSION

Tabs. 1 and 2 present the results of modulus of elasticity (ME) research obtained using ultrasonic and vibro-acoustical methods.

Tab. 1: ME of wood against ultrasound measurements.

Sample No.	Ultrasound speed (m·s^{-1})	Modulus of elasticity (MPa)
1	3 500.00	5 164.22
2	3 333.33	6 132.36
3	3 951.61	8 169.09
4	3 164.56	4 571.80
5	3 630.43	6 249.16
6	3 577.59	6 084.83
7	3 960.78	7 192.42
8	3 762.45	5 755.76
9	4 260.87	8 355.43
10	4 421.52	9 390.10
11	3 783.78	6 727.27
12	3 485.92	6 682.09

Tab. 2: ME of wood against vibration measurements.

Item No.	Sample No.	Length (mm)	Diameter (mm)	Density (kg·m^{-3})	Natural frequency (Hz)	Modulus of elasticity (MPa)
1	1-3	98.0	3.2	421.6	84.0	3 167.4
2	1-4	80.0	5.1	551.9	244.0	3363.0
3	1-5	98.0	6.3	523.2	265.0	5737.6
4	2-3	100.0	3.2	456.5	61.0	2395.7
5	2-4	100.2	3.5	474.1	91.0	3 104.6
6	2-5	83.0	3.6	475.4	176.0	3295.4
7	2-6	101.0	5.7	458.5	226.0	4483.8
8	5-3	98.2	3.3	406.6	71.0	3460.6
9	5-4	98.0	4.8	460.2	162.0	5550.5
10	5-5	98.6	5.6	480.3	225.0	6293.3
11	5-6	70.0	5.9	469.9	509.0	3813.3
12	5-7	99.0	7.5	549.9	313.0	3549.6

The comparative analysis of ME study results obtained using ultrasonic and vibration methods is given in Tab. 3 and Fig. 5.

Tab. 3: Results of statistical processing of ME parameters of wood.

Statistical indicator	Ultrasound method	Vibration method
Mean value (MPa)	6706.211	4017.896
Standard deviation (MPa)	1383.728	1221.480
Dispersion (MPa)	1914703.708	1492014.145
Variation factor (%)	20.634	30.401
Accuracy figure (%)	5.158	7.600
Relative error (MPa)	10.993	16.196
Fisher's variance ratio	1.133	
Correlation factor	0.964	

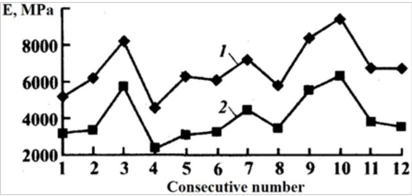


Fig. 5: Modulus of elasticity of wood determined using ultrasonic (1) and vibration (2) methods.

According to these data, the vibration method of defining dynamic ME is as good as the ultrasonic one with respect to accuracy of measurements, which is confirmed by the results of statistical processing. In this case, Fisher's variance ratio expected value for the chosen significance value $p = 0.05$ (i.e. less than in the table) testifies to uniformity of modulus of elasticity values obtained using vibrating and ultrasonic methods. Positive parameter of correlation $r = 0.964$ testifies to comparability of ME values obtained.

However it is important to bear in mind that dynamic modulus of elasticity obtained using ultrasonic measurements surpasses in magnitude the results of vibration studies of this parameter on the same wood samples.

It is essential, that in the first case the parameters of resonant properties determined according to the formula accepted in many countries will be overestimated (Andreyev 1938):

$$K = \sqrt{\frac{E_{dyn}}{\rho^3}} \tag{4}$$

where K - Andreyev's acoustic constant, $m^4/(kg \cdot s)$ characterizing the quality of resonant material against sound radiation;

ρ - density ($kg \cdot m^{-3}$).

Such a conclusion is proved to be true by the results of similar research obtained earlier. The research was conducted on radial-cross-cut cores taken from trunks of mature trees: In case of determining sound propagation speed using the ultrasonic method, the acoustic constant can turn out almost 2 points higher than in case of using the method of resonant frequency. (Fedyukov et al. 2015).

Besides, resonant frequency represents more important information on quality of resonant wood, as with the help of this parameter it is possible to determine logarithmic decrement of longitudinal and bending fluctuations, the characteristic of the speed of fluctuations attenuation and internal friction (viscosity).

There are certain scientific preconditions for doing research in this field. For example, new works began to appear abroad in the field of research related to elastic-viscous properties of not only spruce wood, but even fruit trees for manufacturing a bottom deck of the violin and national musical instruments (Danihelova 2004, Danihelova and Culik 2013, Krauss and Kúdela 2011, Halachan and Spisiak 2015).

Typically, that together with these works scientific research studies appear directed on revealing the opportunity of early diagnostics of standing wood modulus of elasticity as early as at the stage of young growth (Nakanura 1997, Mamdy 1995).

In this, scientific confirmation of interrelation of technical properties of lateral branches and trunk wood, e.g. of a 7-year-old pine, has important practical value (Hsu et al. 2003).

CONCLUSIONS

There are real opportunities for implementing the method of non-destructive diagnostics of technical and resonant properties against wood dynamic modulus of elasticity for young growths and understory of spruce, keeping their viability. Thanks to this, the opportunity appears to form especially valuable forest stands of them.

Determination of this parameter by revealing resonant frequency using the vibration method seems more objective and informative.

REFERENCES

1. Andreyev N.N., 1938: On the tree for musical instruments. Collection of works, CMSRL. M.L., 1:11-18.
2. Aoki, Tsutomu, Yamada Tadashi, 1971: The viscoelastic properties of wood used for musical instruments, Presented partly on the 21st Meeting of the Japan Wood Research Society. Nagoya 42 pp.
3. Blskova, G., Brdarov, N., 2003: Sounding wood acoustic characteristics studies. Collection of scientific reports at 50th anniversary of the Forest Engineering Institute, In: Woodworking and furniture production section, Sofia, Pp 49-53.
4. Bucur, V., 2006: Acoustics of Wood. Springer Verlag Berlin Heidelberg, 393 pp.
5. Danihelova, A., 2004: Relevant physical acoustics of spruce wood as a material for musical instruments. In: Proceedings of the 8th World Conference on Timber Engineering WCTE Lahti, Finland, Pp 491- 49.
6. Danihelova A, Culik, M., 2013: Non-tradition use of mountain ash for production of viola elements. In: Noise and vibration in practice: proceedings of the 18th International Acoustic Conference. Slovak Technical University in Bratislava. Pp 27- 30.
7. Fabisiak, E., 2005: Variability of the basic anatomic elements and wood density in selected wood species. Poznań. Rozprawy Naukowe. 369: 1-176 (in Polish).
8. Fedyukov, V.I., Saldaeva, E.Yu., Tsvetkova, E.M., 2016: Resonance wood microstructure peculiarities. Wood Research 61 (3): 413-422.
9. Fedyukov, V.I., Shurgin, A.I., Saldaeva, E.Yu., Tsvetkova, E. M., 2015: Theoretical studies and measurements of elastic-acoustic performance of wood with different methods for selection of resonant growing crop. Wood Research 60 (3): 417-428.

10. Fedyukov, V.I. 2016: Resonant spruce: Selection on stand, cultivation, target use. Scientific publication. Yoshkar-Ola: VSUT, 256 pp.
11. Ugolev, B.N., 2001: Wood science with basic concepts of timber merchandising. Moscow State Forestry University, 340 pp.
12. Krauss, A., Kúdela, J., 2011: Ultrasonic wave propagation and Young's modulus of elasticity along the grain of Scots pine wood (*Pinus sylvestris* L.) varying with distance from the pith. Wood Research 56 (4): 479-488.
13. Halachan, P., Spisiak, D., 2015: Physical and acoustical characteristics of chosen fruitwoods. In: Modern problems of wood Science, Kostroma. Pp 182-189.
14. Hsu Linda, C.Y., Chauhan, S, King, N., 2003: Modulus of elasticity of stemwood vs branchwood in 7-year-old *Pinus radiate* families, N.Z.J. of Forestry. 33: 35-46.
15. Lindstrom, H., Harris, P., Nakada, R., 2002: Methods for measuring stiffness of young trees. In: Holz als Roh und Werkstoff 60: 165-167.
16. Nakanura, N., 1997: Development of measuring Young's modulus of planting stock, J. of the Jap. For Soc. 79(1): 43-48.
17. Mandy C., Rosenberg P., Bastion J.C. Non-Destructive Assessment Modulus of Elasticity in Genetic Field Tests in France: 20 IUFRO World Congr., Tampere, 7–11 Au-gust, 1995. IAWA Journal, 1995, no. 1, p. 16.
18. Pat. 2439561 RF. IPC G 01 N 33/46. Method of early diagnosing wood resonant properties, V. I. Fedyukov, E. Yu. Saldaeva, A. L. Vasenev, Applicant and patent owner is MSTU. – RU 2439561 C2; appl. 26.032009; publ. 10.01.2012; Bul. of invent. - 2012. - No 1.

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