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Comparison of Viscous Elastic Properties in Wood of Leaf and Coniferous Tree

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The mechanical properties of wood polymeric system are defined in terms of viscous elastic materials. These properties have an impact on relaxation processes for both wooden specimens and wooden articles. In this paper the method of estimation of dynamic modulus of elasticity and coefficient of damping based on resonance vibration is presented. All sorts of trees by wood structure may be classified into leaf and coniferous tree. The structure of wood determines their different properties. Therefore in many cases leafy and coniferous trees are used in different purposes. Spruce (coniferous tree) and oak (leaf tree) wood specimens have been used in the investigation and the viscous elastic properties of these wood types were compared together. The specimens were sawn from three places of central and side boards and they were relatively called “butt-end”, “center” and “top-end”. It was found that modulus of elasticity in central and side boards of oak and spruce varied conversely – in center of oak boards the modulus of elasticity is highest, in center of spruce boards the modulus of elasticity is lowest. The coefficient of damping in both central and side boards of oak and side boards of spruce varied analogically.

Keywords: dynamical modulus of elasticity, coefficient of damping, resonance vibration, spruce and oak wood assortments.

INTRODUCTION

Essential groups of trees are leafy and coniferous [1, 2]. The mechanical properties of wood are mixed distributed in all volume of tree [3 – 5]. This is influenced by peculiarity of structure – different anatomical elements of wood, distribution of grain and etc [6, 7].

The structure of wood determines their mechanical properties. The elements of constructional, music instruments, ships are produced from wood of coniferous trees. The articles of woodworkers, furniture are producible from wood of leafy trees.

A significant part of wooden articles used in airplanes, ship industry undergo dynamic loads [8 – 10]. These loads frequently subject building structures, parts of musical instruments, etc [11 – 13]. Therefore the dynamic investigations of wood are very relevant [14 – 18]. Periodically loading wooden specimens and evaluating their mechanical properties under that regime it is possible to give a complete definition of the behavior of a wooden article when it gets in the zone of dynamic loads.

Various parts of ships, airplanes, building structures and musical instruments make up a complex dynamic system. To investigate those systems, in addition to one of the basic parameters, namely, the modulus of elasticity or coefficient of damping, the amplitude versus frequency response characteristic has to be set up for developing the optimal structure of an article [19, 20]. In most cases they must be known in order to avoid resonance phenomena and also either to increase or decrease vibrations damping. In musical instruments, on the contrary, wood is extensively used for sound intensification [21 – 23]. In both cases of insulating and intensifying the sound the elastic and viscous properties of wood have to be taken into consideration [20].

When manufacturing wooden articles and choosing wood for them the knowledge not only of wood, but of mechanical properties as strength, rigidity, damping, etc., of various wooden parts and joints is of great significance.

It is obvious that different kinds of wood possess different properties which are non-uniformly distributed along the log. Therefore, research in selecting wood for manufacturing the parts of various articles becomes more and more predominant.

The aim of the work is to estimate and to compare mechanical properties in wood of oak and spruce – typical leaf and coniferous trees.

STUDY METHOD AND EQUIPMENT

In many cases mechanical systems are idealized as lumped parameter type, i.e. masses have been assumed to be rigid bodies where all points within the body move in phase, and elastic elements are assumed to have no mass.

When the mass of an investigated body is concentrated in “one point” the equivalent mechanical system is simpler. In this case the investigated specimen can be simulated by means of a lumped parameter system shown in Figure 1 [24]. Frequency of the free oscillations may be calculated in the following way:

$$\varpi = \sqrt{\frac{3EI}{mL^3}}\ , \tag{1}$$

where E is the modulus of elasticity, I is the moment of inertia of the cross-section, L is the length of the assortment.

The analyzed dynamic system does not fully represent all elastic and viscous wood properties distributed along the beam length when its mass is not concentrated at one of its ends. That beam can be represented by a mechanical

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system with an infinite number of degrees of freedom [24]. The basic frequency of free vibrations of freely placed beam is calculated in the following way.

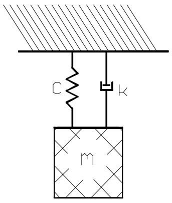


Fig. 1. Scheme of dynamic model of the investigated specimen: *m* – the mass of a specimen; *c, k* – the coefficients of rigidity and mean resistance of the specimen, respectively

$$f = \frac{A}{2\pi l^2}\sqrt{\frac{EI}{\rho S}}\,, \qquad (2)$$

where l is the beam length, I is the cross-section inertia moment, f is the resonance frequency of i-th form vibrations, A is the coefficient, characterizing the method of fastening beams ends and its bending forms.

Viscous properties of the investigated specimen are evaluated from the curve of resonance vibrations i.e. from the amplitude versus frequency response characteristic [25]:

$$\mathrm{tg}\delta \approx \frac{\Delta f}{f_r}\,, \qquad (3)$$

where $\mathrm{tg}\delta$ (r. u.) is the general characteristic of the specimen internal friction – tangent of the losses angle, f_r is the resonance frequency, Δf is the frequency band width.

It is obvious that resonance vibrations of specimens properly characterize elastic and viscous properties of the material they are made of. This procedure is appropriate for analysis of separate wooden parts by rendering them the shape of a beam [26]. Based on the above-mentioned procedure a testing unit for investigating the properties of wooden specimens has been developed (Figure 2).

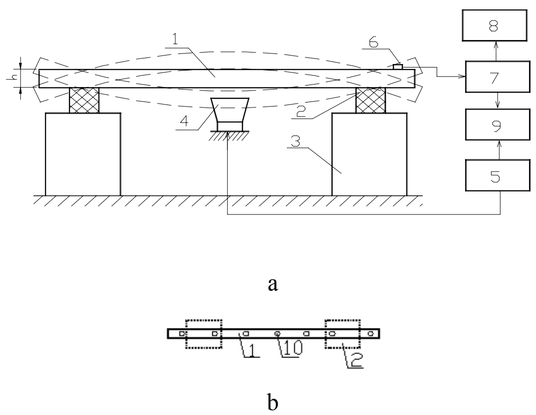


Fig. 2. Test stand of wood articles (a) and location scheme of vibration measurement points in the case of a beam (b): 1 – wood assortment and its bend form; 2 – elastic elements; 3 – massive supports; 4 – acoustic vibrator; 5 – generator of electric oscillations; 6 – sensor; 7 –measuring device; 8 – oscilloscope; 9 – phasometer; 10 – fastening points of the sensor

The beam under testing is placed on two elastic elements (Fig. 2, b). These elements are made of foam $(120 \times 120 \times 100)$ mm and fastened to the massive supports 3. An acoustic vibrator 4, which is controlled by the generator 5 of electrical signals, induces vibrations of the studied assortment 1. These vibrations are recorded by a sensor 6, attached to the studied assortment 1. Changing the frequency of the generator 5, resonance vibrations of the studied assortment are induced. They are measured by the measuring device 7. The form of vibrations is observed on the screen 8 of the oscilloscope. To determine bending direction of an assortment, vibration phase is measured by a phasometer 9. For this purpose, signals from the measuring device 7 and the generator 5 are sent to the phasometer 9.

The tested beam is freely placed on elastic elements 2, thus this case corresponds to the extreme conditions of an unfastened beam. Assortment vibrations were measured within 20 Hz – 2000 Hz range (error of measurement is ±0.1 Hz).

EXPERIMENTAL DATA

Oak and spruce wood scantlings have been used in the investigation. The scantlings were two types – sawed from central and side boards. The scantlings of both types were brought to three groups – the scantlings from the butt-end (about 500 mm from but of log), from center and from top-end (about 500 mm from end of top). For the studies 70 oak scantlings and 103 spruce scantlings were used (in one group were 11 – 12 oak and 16 – 18 spruce scantlings). Sawing scheme of scantlings and scantling drawing are provided in Figure 3.

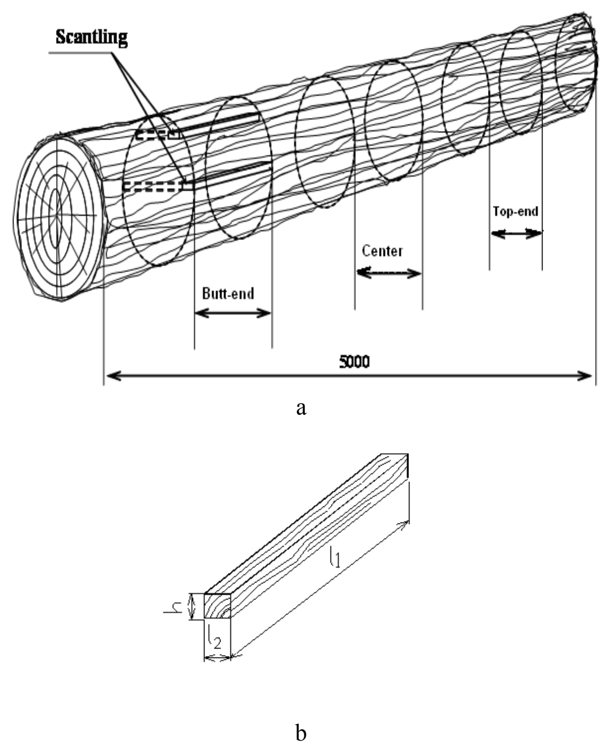


Fig. 3. The scheme of scantling sawing from a log (a) and scantling drawing (b): l_1, l_2, h – length, width, height of scantling

The scantlings were sawn along the grain from 5 m long log. The oak scantlings dimensions were $(670 \times 60 \times 30)$ mm, densities of the scantlings were – 630 kg/m^3 – 780 kg/m^3, moisture content – 10.3 % – 13.7 %. The spruce scantlings dimension were $(400 \times 40 \times 14)$ mm, densities of the scantlings were – 380 kg/m^3 – 510 kg/m^3, moisture content – 7.6 % – 10.9 %. The scantlings were measured by a vernier calliper (0.05 mm and 0.02 mm accuracy) and they were weighed by electronic scales (0.01 g accuracy). Wetness of the scantlings was determined by a hydrometer. Dimensions of the scantlings were like usable in making of glued-up panels.

The dynamic modulus of elasticity and coefficient of damping of wood were evaluated by referring to (2) and (3) expressions. Distribution of mean values of modulus of elasticity and coefficient of damping in the central and side boards of oak is provided in Figure 4. It can be seen (Fig. 4), that "moving" towards the top – end, modulus of elasticity and coefficient of damping increases. Estimated, that increase of modulus of elasticity is considerably drastic. It was found that the lowest modulus of elasticity in the central oak board comprised 9000 MPa, while the highest 13100 MPa. In the side oak board the values of modulus of elasticity varied within 9700 MPa – 13600 MPa range. 11 – 12 scantlings were evaluated to determine modulus of elasticity of one zone. Experimental error values of modulus of elasticity were by 0.6 % (absolute error 40 MPa – 95 MPa).

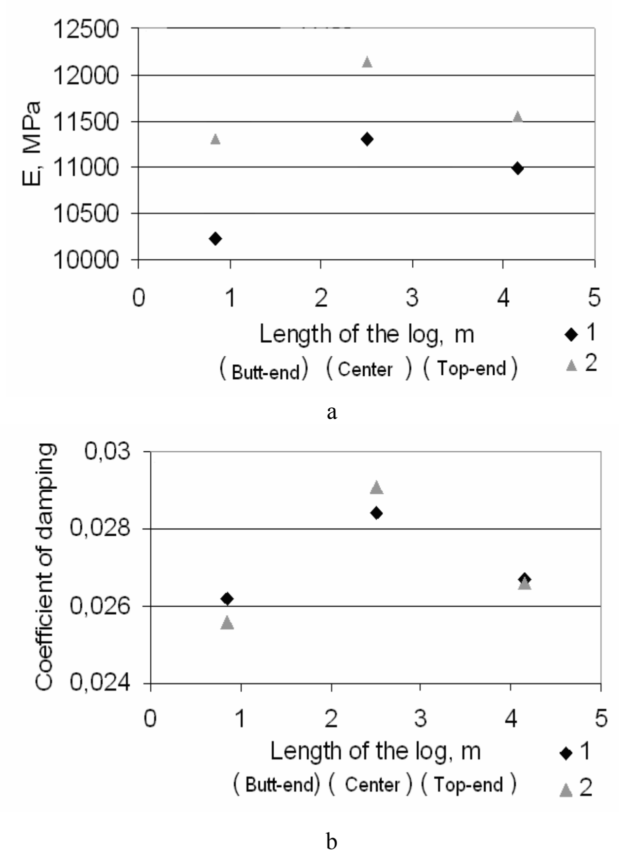


Fig. 4. Distribution of mean modulus of elasticity (a) and coefficient of damping (b) along the oak log length: 1 – central boards, 2 –side boards

It was obtained that in the side boards modulus of elasticity is higher than in the central ones. Analyzing amplitude-frequency characteristics of scantlings, viscous properties (coefficient of damping) of oak wood were estimated too. It was obtained that in the central board coefficient of damping varied within 0.0179 – 0.0332, while in the side board – within 0.0174 – 0.0398 range. Experimental error values of coefficient of damping were by 0.3 % (absolute error $(4 – 10) \times 10^{-5}$ r. u.).

As can see, variation of modulus of elasticity in log were about 10 % of average value (about 1000 MPa) and variation of coefficient of damping were about 7 % of average value (about 0.002 r. u.). Error of measurement of these values is by 1 %.

The highest values of modulus of elasticity are registered in the central part of log (in central boards 11300 MPa, while in side boards – 12100 MPa). Towards the ends, wood modulus of elasticity slightly decreases (by about 7 %).

It has been ascertained that the highest coefficient of damping was recorded in the middle of side and central boards (0.0291 and 0.0284, respectively). Coefficient of damping in the butt end of central boards is 0.0262, in the middle – 0.0284, in the top end – 0.0267 [1, 2].

It is known [1, 2] that modulus of elasticity of oak wood along the grain may vary within 9200 MPa – 15100 MPa, coefficient of damping – about 0.034.

Analogically viscous elastic properties of spruce scantlings sawn along the grain were estimated. It was found that the lowest modulus of elasticity in the center of central board comprised 10600 MPa, while the highest 12800 MPa – in the side board top-end. It was obtained that in the central board coefficient of damping varied within 0.010 – 0.018, while in the side board – within 0.010 – 0.019 range. 16 – 18 scantlings were evaluated to determine modulus of elasticity of one zone

It is known that modulus of elasticity of spruce wood along the grain may vary within 6600 MPa – 17200 MPa, coefficient of damping – 0.005 – 0.036 [1, 2, 22, 27].

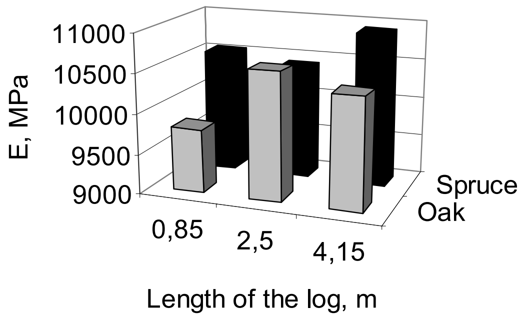
The highest values of modulus of elasticity are registered in the top of log. (in central boards butt-end – 10800 MPa, top-end – 11100 MPa, while in side boards – 12400 MPa and 12800 MPa, respectively). In center of boards wood modulus of elasticity slightly decrees (by about 5 %).

In central boards towards the top-ends, wood coefficient of damping increases (in butt-end – 0.0106, in top-end – 0.0111). The highest values of coefficient of damping are registered in center of sideboards – 0.0113, and in tops – lesser (in butt-end – 0.0107, in top-end – 0.0105). It was found that distribution of coefficient of damping in side boards is more than in central boards (by 2 times).

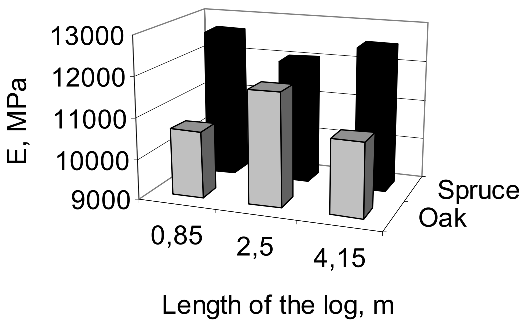
Study results were processed statistically. It has been ascertained that variation coefficient of modulus of elasticity of oak specimens, sawn from central boards of log, is 11.5 %, from side boards – 13 %. It was found that variation coefficient of coefficient of damping of oak specimens, sawn from central boards of log, is 28.5 %, from side boards – 20 %. Variation coefficient of modulus of elasticity of specimens, sawn from central and side boards of spruce log is respectively 18.5 % and 16 %, of coefficient of damping – about 22 %.

As can see in the outer part of log variation coefficients of modulus of elasticity of oak and spruce are close (respectively 13 % and 16 %) while in the centre of spruce log it is higher (respectively 11 % and 18 %). In the damping case, the highest variation coefficient in the outer part of log was found in the butt-end of oak boards (28 %) and in the top-end of spruce boards (17 %), while in the center of log – in the top-end of oak (34.5 %) and butt-end of spruce boards (27 %).

Comparison results of oak and spruce viscous elastic properties are provided. Variation of modulus of elasticity in oak and spruce wood is presented in Figure 5.



a



b

Fig. 5. Distribution of modulus of elasticity in oak and spruce log along the grain: a – in central boards, b – in side boards

It has been ascertained that in oak wood the highest average modulus of elasticity is found in the middle of both central and side boards. In the butt and top ends it is lower. In spruce wood, on the contrary, in the middle modulus of elasticity is the lowest. Modulus of elasticity of central oak boards is 10800 MPa that of side boards – 11700 MPa, in spruce wood it comprises respectively 10900 MPa and 12300 MPa. It was determined that in both cases in the central part of log modulus of elasticity is lower than in the periphery (7 % and 12 %, respectively). In central oak board modulus of elasticity varied within a wider range than in spruce boards (7 % and 4 %, respectively). It was found that average modulus of elasticity of oak wood is about 2 % more than spruce. That correspond proportion of known this values [1, 2].

Else estimated, that modulus of elasticity of oak wood is about 10 % lesser that spruce wood. Especially this parameter is differing in side boards.

It has been ascertained that coefficient of damping of spruce wood is by about 2.5 times lower than that of oak (for oak – 0.0272, while for spruce – 0.0109). In the middle of central and side boards of spruce coefficient of damping is lower by about 2.6 times, while in the top end of central boards and in the butt end of side boards – by about 2.4 times. It has been determined that coefficient of damping of oak wood in different log zones of the central boards differs by about 7 %, in side boards – by about 12 %. In spruce wood these differences are lower (4.5 % and 7 %, respectively).

It is known, that average coefficient of damping of oak and spruce wood is close. Used in investigation oak specimens coefficient of damping correspond known values. It was found that coefficient of damping of spruce wood is rather lesser. The density of following specimens were more, rings were narrow (about 1 mm – 2 mm width) and regular form. These properties are typical for resonance wood.

Analyzing the variation of modulus of elasticity and coefficient of damping, in general, it was obtained that in the wood of both assortments change of coefficient of damping is inversely proportional to modulus of elasticity.

In order to use wood for manufacturing various purpose parts the properties of wood as viscous elastic material have to be considered in different places of the log.

CONCLUSIONS

1. The developed testing unit of dynamic parameters of wood specimens made the investigation of small size specimens sawn in different places of a log possible.
2. It was found that modulus of elasticity in central and side boards of oak and spruce varied conversely – in center of oak boards the modulus of elasticity is highest (about 25 %) than in the other parts of a log, in center of spruce boards the modulus of elasticity is lowest (about 17 %). The coefficient of damping in both central and side boards of oak and side boards of spruce varied analogical – the highest coefficient of damping is in center of boards (about 10 %).
3. It was obtained that modulus of elasticity of both oak and spruce in different parts of a log differ by up to 20 %, while coefficient of damping – by up to 40 %.
4. It was ascertained that modulus of elasticity of oak and spruce wood along the grain is close (oak average modulus of elasticity is 11235 MPa, spruce – 10987 MPa).
5. It was obtained that for typical properties of resonance spruce wood coefficient of damping of this wood is 2.5 time lesser than oak.

REFERENCES

1. **Wagenführ, R.** Bildlexikon Holz. Leipzig. Carl Hanser Verlag, 2004: 370 p.
2. **Wagenführ, R**. Holzatlas. Leipzig. Fachbuchverlag, 2000: 708 p.

3. **So, Ch., Via, B. K., Groom, L. H., Schimleck, L. R., Shupe, T. F., Kelley, S. S., Rials, T. G**. Near Infrared Spectroscopy in the Forest Products Industry *Forest Products Journal* 54 (3) 2004: pp. 6 – 16.

4. **Wood, J., McDonald, D., Miles, K., Browne, T.** Multivariate Analysis of Seasonal Pulp Quality Variations in a TMP Mill *Pulp & Paper Canada* 105 (10) 2004: pp. 35 – 43.

5. **Perre, P., Turner, I. W.** A Heterogeneous Wood Drying Computational Model that Accounts for Material Property Variation across Growth Rings *Chemical Engineering Journal* 86 (1 – 2) 2002: pp. 117 – 131.

6. **Huang, C.-L., Lindstrom, H., Nakada, R., Ralston, J.** Cell Wall Structure and Wood Properties Determined by Acoustics – a Selective Review *Holz Roh- und Werkstoff* 61 (5) 2003: pp. 321 – 335.

7. **Yang, J. L., Evans, R.** Prediction of MOE of Eucalypt Wood from Microfibril Angle and Density *Holz Roh- und Werkstoff* 61 (6) 2003: pp. 449 – 452.

8. **Bata, M.** Effects on Buildings of Vibrations Caused by Traffic *Building Science* 6 (4) 2003: pp. 221 – 246.

9. **Soda, S.** Role of Viscous Damping in Nonlinear Vibration of Buildings Exposed to Intense Ground Motion *Journal of Wind Engineering and Industrial Aerodynamics* 59 (2 – 3) 1996: pp. 247 – 264.

10. **Luo, X.** Development of Visco-elastic Composite Panels for Increasing Damping in Hospital Buildings. Multidisciplinary Center for Earthouake Engineering Research, State University of New York, 2000.

11. **Lam, F., Barrett, J. D., Nakajima, S.** Properties of Hem – Fir Used in Japanese Post and Beam Housing *Forest Product Journal* 51 (5) 2001: pp. 79 – 87.

12. **Cai, Z., Hunt, M. O., Ross, R. J., Soltis, L. A.** Static and Vibration Moduli of Elasticity of Salvaged and New Joists *Forest Products Journal* 50 (2) 2000: pp. 35 – 40.

13. **Malkin, A. Ya.** Experimental Methods of Polymer Physics. Edit. Moscow, Mir Publishers, 1983: 520 p. (in Russian).

14. **Cai, Z., Ross, R. J., Hunt, M. O., Soltis, L. A.** Plot Study to Examine Use of Transverse Vibration Nondestructive Evaluation for Assessing Floor Systems *Forest Products Journal* 52 (1) 2002: pp 89 – 93.

15. **Wang, X., Ross, R. J., Mattson, J. A., Erickson, J. R., Forsman, J. W., Geske, E. A., Wehr, M. A.** Nondestructive Evaluation Techniques for Assessing Modulus of Elasticity and Stiffness of Small – Diameter Logs *Forest Products Journal* 52 (2) 2002: pp. 79 – 85.

16. **Jönsson, J., Svensson, S. A.** Contact Free Measurement Method to Determine Internal Stress States in Glulam *Holyforschung* 58 2004: pp. 148 – 153.

17. **Kumar, S.** Genetic Parameter Estimates for Wood Stiffness, Strength, Internal Checking, and Resin Bleeding for Radiate Pine *Canadian Journal of Forest Research* 34 (12) 2004: pp. 2601 – 2610.

18. **Charpentier, P., Choffel, D.** The Feasibility of Intrinsic Signature Identification for the Traceability of Pieces of Wood *Forest Products Journal* 53 (9) 2003: pp. 40 – 46.

19. **Nikiforov, A. S.** Acoustics Designing of Ship Structures. Leningrad, 1990: 199 p. (in Russian).

20. **Molin, N. E., Lindgren, L. E., Jansson, E. V.** Parameters of Violin Plates and their Influence on the Plate Modes *Journal Acoustical Society America* 83 (1) 1988: pp. 281 – 291.

21. **Ek, L., Jansson, E. V.** Modal Properties of Wooden Plates Determined by Tv-Holography and Electroacoustical Methods *Journal of Sound and Vibration* 111 (1) 1986: pp. 115 – 124.

22. **Molin, N. E., Tinnsten, M., Wiklund, U., Jansson, V.** FEM – Analysis of an Orthotropic Shell to Determine Material Parameters of Wood and Vibration Modes of Violin Plates *STL – QPSR* 4 1984: pp. 11 – 37.

23. **Burcle, L., Grissino-Mayer, H. D.** Stradivari, Violins, Tree Rings, and the Maunder Minimum: a Hypothesis *Dendrochronologia* 21 (1) 2003: pp. 41 – 45.

24. **Broch, J. T.** Mechanical Vibrations and Shock Measurements. Grostrum, K. Larsen and Son, 1984: 370 p.

25. **Vobolis, J., Aleksiejūnas, M.** Investigation of Wood Mechanical Properties by the Resonance Vibrations Method *Materials Science* (*Medžiagotyra*) 9 (1) 2003: pp. 139 – 143.

26. **Albrektas, D., Vobolis, J.** Modeling and Study of Glued Wood Panel *Materials Science* (*Medžiagotyra*) 10 (4) 2004: pp. 370 – 373.

27. **Bucur, V.** Acoustics of Wood. Berlin, Springer – Verlag, 2006: 393 p.

DOI: 10.5755/j02.ms.26302