421. Estimating wood panels anisotropic properties by resonance vibrations method

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Abstract. In this paper the transverse resonance vibrations of glued-up panels and particle boards are under investigation. The viscous elastic properties of these articles are evaluated based on the theory of resonance vibrations.
The calculating methods of mechanical systems and elastic bodies with infinity degree of freedom and finite elements and accesses to apply for wood articles are considered.
It is shown that through their structure some modes of rectangular wood panels accords modes of elastic isotropic beam and their theoretical calculations of beam vibrations can be applicable.
Anisotropic properties of wood panels are evaluated. It was estimated that the resonance frequency in plane of panel by 5 % and width of band of amplitude – frequency characteristic – by two times can vary.
The results are obtained by estimating the modulus of elasticity and the damping coefficient of wood panels.
Keywords: resonance vibrations, glued-up panel, particle board, modulus of elasticity, coefficient of damping, amplitude of vibrations

Introduction

In the production of various wood articles it is necessary to choose wood of appropriate type, and to determine and foresee its properties as well as the quality of an article.

Many wood articles must feature good strength and elasticity properties. Other articles, in contrast, must damp well the oscillations of various frequencies, i.e., to feature appropriate viscous properties.

Wood is widely used as a building material. The columns, beams, floor and other constructional elements are made of it. In most of these cases strength and elasticity properties are important.

Many accessories of musical instruments should also feature analogous properties. One of the most important elements is the panels of glued-up wood – sounding-boards.

On the other hand, wooden ceilings and partition walls should insulate vibrations and noise quite well. These requirements should be met particularly by wooden floor systems when laminated boards of cuttings are often used as a substitute.

Inner partitions, walls are a very important part of buildings. With their help the space of the building is divided into individual premises. Often inner partition walls are produced of wood of various types, and of particle boards. Almost in all cases inner partition walls should satisfy an important requirement, i.e., good sound insulation. Cases of wooden musical instruments, fitting elements and other should satisfy analogous requirements.

Beside the impacts that affect constructional elements, their oscillations are often excited by the noise. In a general case the insulation of construction oscillations increases when its mass is increased. Rigidity of construction has a significant influence in this case. Particularly rigid constructions insulate the oscillations better.

A miscellaneous evaluation of mechanical properties is usually performed in the dynamic analysis of wood samples and articles. In many cases the oscillations are used in the research. The frequency of oscillations allows evaluating a dynamic modulus of elasticity and the dissipation of energy, i.e., the damping coefficient [1, 2, 3].

Many wooden articles have the shape of a plate or beam. For a dynamic research of such bodies, the resonant oscillation method is used [1, 4, 5, 6].

It is known that the velocity of mechanical oscillations' spread depends on the modulus of elasticity and the density of the material [7, 8, 9, 10]:

$$E = c^2 \cdot \rho , \quad (1)$$

where c – velocity of oscillations' spread in a material; ρ - density.

In the measurements the oscillations of sound frequency and ultrasound are used. Referring to the velocity of oscillation spread of various frequencies, not only balks and planks, but also uncut trees are considered [11].

In the case of resonant oscillations, after determining the resonant frequency and other parameters of assortment being studied, its modulus of elasticity may be calculated.

With application of this method, plates, glued-up panels and accessories of musical instruments are analysed [4, 5, 12].

Analogous analyses are made using free oscillations of the assortments. This method is often used in sorting wood assortments [13]. The assortment transported by a conveyor is hit, and the oscillations of the assortment are registered by a microphone. It was established that when sorting balks and floor systems, the location of a strike does not have any influence on the resonant frequency of a separate assortment, however, the resonant frequencies of separate assortments are different [14, 15, 16].

For sound insulation the wood of various types, or a special construction are used [17, 18, 19]. It is in particular important for wooden buildings, where oscillations are excited by transport movement, earthquakes, etc. In various building constructions the damping coefficient of used panels should be also increased [19].

Thus, the evaluation of viscous elastic properties of wood is an urgent task.

When oscillations of the assortments are excited by striking, the oscillations of several frequencies are excited during the strike. Without evaluation of the oscillation mode, in many cases the modulus of elasticity is difficult to assess. In the analysis of the curve of dying-out of oscillations, it is hard to assess the damping coefficient correctly.

By using the resonant oscillations, the amplitude-frequency characteristics and modes may be estimated precisely. Regardless of the fact that wood is an anisotropic material, in some cases wood assortments may be analysed as quasiisotropic bodies, assuming the change of their oscillation parameters is not significant, and average values of their variation may be operated with.

The objective of the study is to evaluate the spread of resonant oscillations' frequency and the damping coefficient of wood panels with rectangular plate type and particle boards in the points of the assortment plane.

Methods and Equipment of Tests

Wood is an anisotropic material. In general case when analysing wood articles with an application of oscillations, they may be analysed only approximately in the form of concentrated parameters' system.

Applying the discretisation principle, wood articles should be analysed in the form of the system with n degrees of freedom (Fig.1):

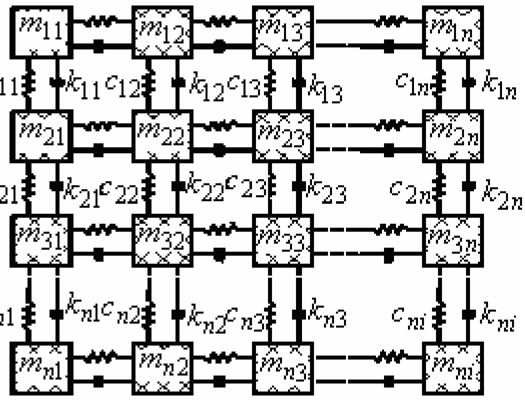


Fig. 1. The mechanical model of a wood panel (cuttings board): $c_{11\text{-}nn}$ – rigidity coefficients; $k_{11\text{-}nn}$ – viscosity (damping) coefficients; $m_{11\text{-}nn}$ – masses of elements

The movement equations of such system would be written down in the following way [20]:

$$M\left\{\ddot{q}\right\} + K\left\{\dot{q}\right\} + C\left\{q\right\} = \left\{Q\right\}, \qquad (2)$$

where
$$M = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2n} \\ - & - & - & - \\ m_{n1} & m_{n2} & \dots & m_{ni} \end{bmatrix};$$

$$K = \begin{bmatrix} k_{11} & k_{12} & \dots & k_{1n} \\ k_{21} & k_{22} & \dots & k_{2n} \\ - & - & - & - \\ k_{n1} & k_{n2} & \dots & k_{ni} \end{bmatrix}; \quad C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ - & - & - & - \\ c_{n1} & c_{n2} & \dots & c_{ni} \end{bmatrix};$$

$$\{Q\} = \begin{matrix} Q_1 \\ Q_2 \\ --- \\ Q_n \end{matrix}; \quad \{q\} = \begin{matrix} q_1 \\ q_2 \\ --- \\ q_n \end{matrix}$$

By exciting such system, n resonant frequencies are obtained.

While applying the method of finite elements, such system (wood board) is divided into the number of finite elements (masses), by evaluating the rigidity and the damping coefficients of every zone. A complex of differential equations for every finite element is worked out by later collecting the matrixes of elements into a global matrix.

While working out oscillations of such systems and determining appropriate modes, the constancy of rigidity and the damping members are adopted.

In wood as an anisotropic material, the rigidity and damping are continuously distributed along entire size of the article [6]. In this way when applying theoretical calculations of oscillations of these bodies for wood articles of balk or plate shape, it is assumed that alteration of these parameters is not significant and their average values are used.

A special stand was used for the tests [6].

After exciting the resonant oscillations and determining the average resonant frequency and other parameters of the studied assortment, the mean modulus of elasticity is calculated.

$$E = \frac{f_r^2 4\pi^2 \rho S l^4}{I A^2}, \qquad (3)$$

where f_r – resonant frequency; l – sample length; ρ - density; S – area of assortment's cross-section; I – moment of inertia of a cross-section; A – coefficient depending on the type of the assortment attachment and oscillations mode.

After analogically evaluating the amplitude-frequency characteristic, the damping coefficient of the assortment was established (tangent of loss angle) [1, 20]:

$$tg\delta \cong \frac{f_2 - f_1}{f_r}, \qquad (4)$$

where f_r – resonant frequency ; f_1, f_2 – frequencies when the resonant amplitude decreases by $\sqrt{2}$ times

The studied assortments were classified into the number of finite elements (zones). In each of them the resonant frequency and damping coefficient, i.e. the spread of parameters in the plane of the assortment, were measured. Also a variation in oscillations amplitude was assessed.

Research Results

The glued-up panels of oak scantlings (3 pcs.) and particle boards of different manufacturers (12 pcs.) were used in the research.

700×700 mm dimensions of panels and boards were chosen according to the construction of a test stand. The thickness of glued-up panels and particle boards was 30 mm and 18 mm respectively, and its humidity did not exceed 12 %.

The density of panels varied between 670 and 730 kg/m^3, and the one of boards was in the range of 640 - 700 kg/m^3. Tests were made in the laboratory conditions, where the temperature was about 20 ^{0}C, and relative air humidity constituted about 60 %.

The dimensions of the studied assortments were measured by using sliding callipers (length and width - within 0.05 mm, width – within 0.02 mm), and the mass was measured by dynamometer (to within 50 g).

While adjusting the frequency of oscillations' generator, the amplitude-frequency characteristics of glued-up panels and particle boards were determined in separate zones of the assortments (oscillation measurement points). They are shown in Fig. 2.

By measuring oscillations in separate zones of the panels, it was determined that different zones vibrated with different frequencies. In addition, it was established that a different number of resonant frequencies was registered within the frequency range of 20 – 2000 Hz in separate zones: in some it reached 12, in others – 15.

In seeking to increase the sharpness of measurement, the amplitude of oscillations acceleration is measured.

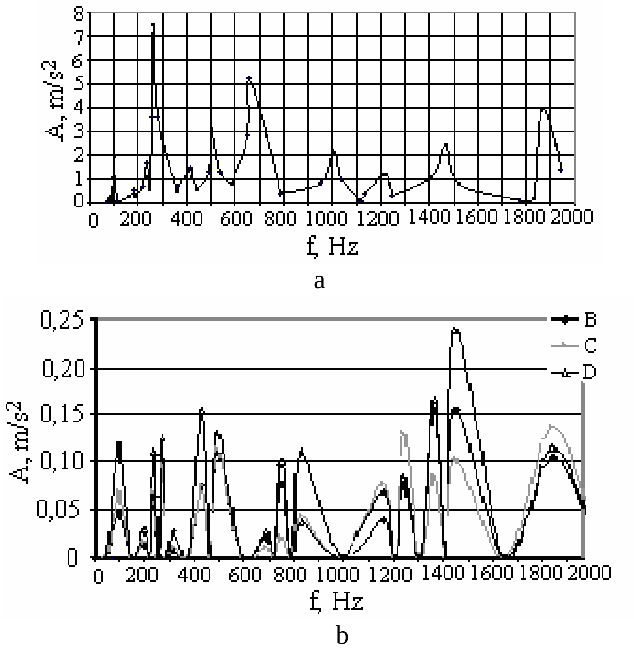


Fig. 2. The amplitude – frequency characteristics of particle boards (a) and glued-up panel (b) in one of the characteristic zones

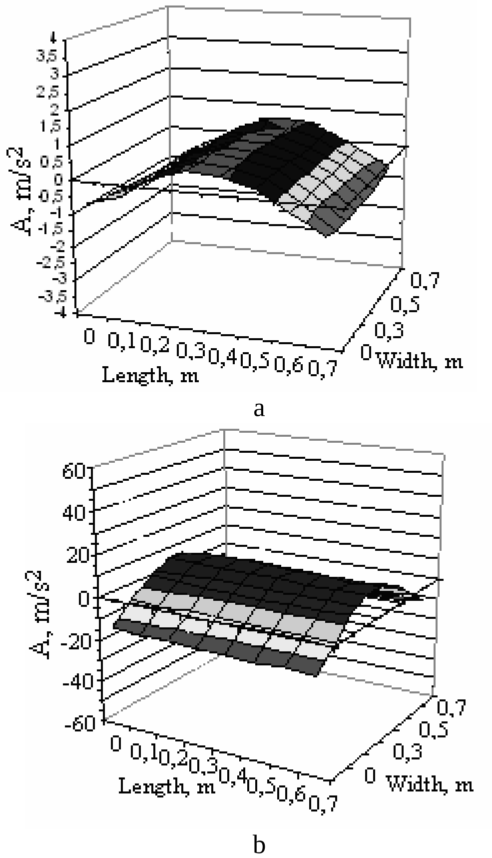
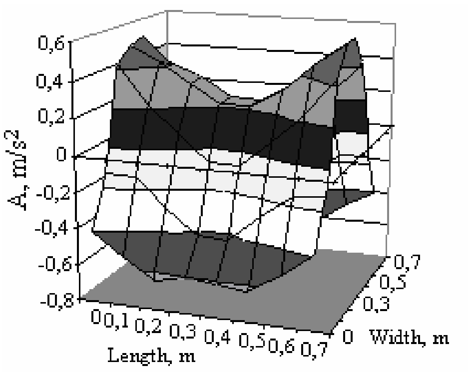


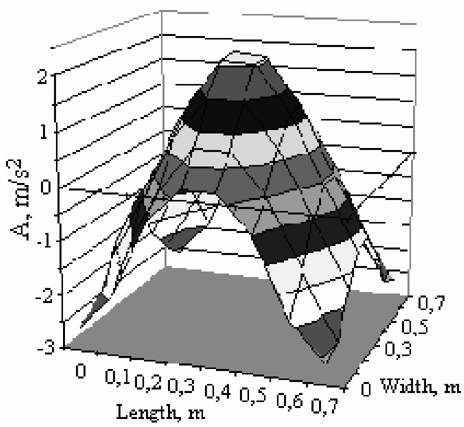
Fig. 3. The modes of glued-up panel at its vibration along the grain (a) and across the grain (b): a- average resonant frequency 289 Hz; b – 90 Hz

In order to obtain characteristic modes of oscillations, the arithmetic mean values of the resonant frequencies were used. Measurements were made in 64 points of panels' plane.

In the course of tests it was determined that due to clearly expressed properties of wood along and across the grain, and due to the density distribution of particle boards in the case of resonant oscillations of appropriate frequencies, these assortments conform to the laws of oscillations of beam being deformed (Fig.3). The modulus of elasticity and the damping coefficient agreeably to (3) and (4) expressions are evaluated as equivalent values in an appropriate direction of inflection.



a



b

Fig. 4. The modes of particle boards when they vibrate at different, perpendicular to each other directions: a – average resonant frequency 84.1 Hz; b – 100 Hz

As it can be seen from the amplitude-frequency characteristics (Fig.2), and modes (Fig. 3, 4), the oscillation amplitudes of panels and boards also differed significantly.

In seeking to determine viscous elastic properties more precisely, the regularities of the distribution in assortment plane of oscillation amplitude of resonant frequency and damping coefficient were estimated.

Values of amplitude and resonant frequency in the plane of one of the glued-up panels, when it vibrates at the frequency of about 91 Hz (the mode, when panel bends across the grain, is close to the theoretical one of an isotropic beam), are presented in Tables 1 and 2.

Table 1. Mode of the value (m/s^2), of the oscillation amplitude of glued-up panel, when it vibrates across the grain is akin to theoretical mode of isotropic beam

p/A		p/A		p/A		p/A		p/A		p/A		p/A		p/A	
1	0,62	9	0,34	17	0,32	25	0,6	33	0,56	41	0,3	49	0,25	57	0,82
2	0,76	10	0,32	18	0,29	26	0,58	34	0,52	42	0,31	50	0,26	58	0,96
3	0,81	11	0,40	19	0,25	27	0,6	35	0,5	43	0,3	51	0,29	59	0,98
4	0,85	12	0,32	20	0,30	28	0,56	36	0,49	44	0,32	52	0,24	60	0,95
5	0,91	13	0,34	21	0,19	29	0,51	37	0,5	45	0,22	53	0,22	61	0,93
6	0,92	14	0,34	22	0,21	30	0,53	38	0,52	46	0,25	54	0,22	62	0,91
7	0,9	15	0,32	23	0,2	31	0,34	39	0,54	47	0,25	55	0,23	63	0,82
8	0,86	16	0,34	24	0,19	32	0,53	40	0,58	48	0,32	56	0,21	64	0,68

* where *p* – running number of a point, *A* – amplitude m/s^2 (the amplitude of oscillations acceleration is measured to increase the sharpness of measurement)

Table 2. The mode of the value (Hz) of the resonant frequencies of a glued-up panel, when it vibrates across the grain, is akin to the theoretical mode of isotropic beam

p/f		p/f		p/f		p/f		p/f		p/f		p/f		p/f	
1	90,6	9	90,7	17	90,8	25	90,6	33	90,7	41	90,5	49	90,6	57	90,3
2	90,5	10	90,6	18	90,7	26	90,7	34	90,8	42	90,6	50	90,5	58	90,3
3	90,5	11	90,6	19	90,8	27	90,7	35	90,8	43	90,6	51	90,7	59	90,3
4	90,6	12	90,7	20	90,8	28	90,6	36	90,8	44	90,5	52	90,5	60	90,4
5	90,5	13	90,8	21	90,8	29	90,7	37	90,8	45	90,8	53	90,8	61	90,4
6	90,5	14	90,6	22	90,8	30	90,7	38	90,9	46	90,8	54	90,8	62	90,6
7	90,6	15	90,6	23	90,6	31	90,7	39	90,8	47	90,7	55	90,8	63	90,5
8	90,5	16	90,9	24	91	32	90,7	40	90,7	48	90,8	56	91,1	64	90,7

* where *p* – running number of a point, *f* – resonant frequency, Hz

It can be seen that the mode, when the panel bends across the grain, is akin to the mode of isotropic beam, the highest amplitude in the direction of inflection is at the edges and in the middle zone (the amplitude reaches up to 0.95 m/s^2). The amplitude at the edges in the middle zone of a panel in perpendicular direction is the biggest, and in the middle – the lowest. It was determined that when panel vibrates at the mode along the grain akin to theoretical mode of isotropic beam, the oscillation amplitude is up to 20 times bigger.

In Figure 5 the regularities of oscillations amplitudes of panel of glued-up wood without considering oscillation phase, and the variation of resonant frequency in the plane are presented.

It was determined that the amplitudes of different zones' oscillations differ up to 2,5 times, and the change in a resonant frequency may reach 3 – 5 %.

Table 3. The values (m/s^2) of oscillations amplitude of a particle board when it vibrates at the mode akin to the theoretical mode of isotropic beam

p/A		p/A		p/A		p/A		p/A		p/A		p/A		p/A	
1	2,87	9	2,00	17	0,60	25	0,23	33	0,23	41	0,58	49	1,90	57	2,85
2	2,35	10	1,32	18	0,09	26	0,90	34	0,90	42	0,08	50	1,40	58	2,20
3	1,80	11	0,54	19	0,86	27	1,68	35	1,70	43	0,83	51	0,58	59	1,80
4	1,28	12	0,12	20	1,38	28	2,20	36	2,20	44	1,30	52	0,12	60	1,35
5	1,30	13	0,12	21	1,40	29	2,15	37	2,15	45	1,36	53	0,12	61	1,30
6	1,90	14	0,55	22	0,94	30	1,66	38	1,65	46	0,86	54	0,55	62	1,85
7	2,72	15	1,10	23	0,12	31	0,82	39	0,87	47	0,12	55	1,30	63	2,55
8	3,70	16	2,00	24	0,68	32	0,16	40	0,20	48	0,67	56	2,00	64	3,43

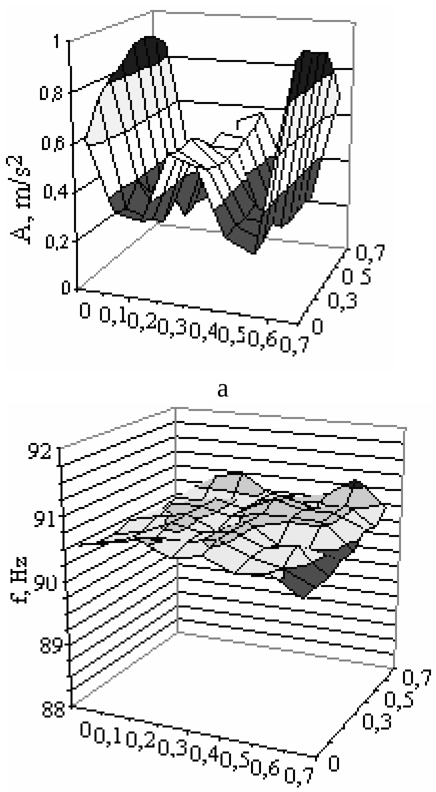
* where *p* – running number of a point; *A* – amplitude m/s^2

Table 4. The values (Hz) of resonant frequency of oscillations of particle board when it vibrates at the mode akin to the theoretical mode of isotropic beam

p/f		*p/f*		*p/f*		*p/f*		*p/f*		*p/f*		*p/f*		*p/f*	
1	99,7	9	100,5	17	101,1	25	101,0	33	101,0	41	101,1	49	100,6	57	99,9
2	100,3	10	100,8	18	101,0	26	101,2	34	101,2	42	101,1	50	101,0	58	100,2
3	100,7	11	100,9	19	101,0	27	100,9	35	100,8	43	101,0	51	100,9	59	100,6
4	100,8	12	100,8	20	100,7	28	100,8	36	100,8	44	100,7	52	100,8	60	100,7
5	100,7	13	100,8	21	101,0	29	100,8	37	100,8	45	100,6	53	100,8	61	100,7
6	100,5	14	100,9	22	101,0	30	100,8	38	100,9	46	101,0	54	101,0	62	100,6
7	100,3	15	100,9	23	101,1	31	101,1	39	101,1	47	101,1	55	101,2	63	100,2
8	99,4	16	100,3	24	101,0	32	100,9	40	101,1	48	101,0	56	100,5	64	99,8

- where *p* – running number of a point; *f* – resonant frequency, Hz
-

It was established that angles of particle board (with amplitude up to 3,7 m/s^2) and central part (up to 2,15 m/s^2) vibrated at the highest amplitudes. It was determined that the resonant frequencies of board angles' zones were lower than 100 Hz, while the frequency dominating in other zones varied in the range 100,3 – 101,2 Hz.

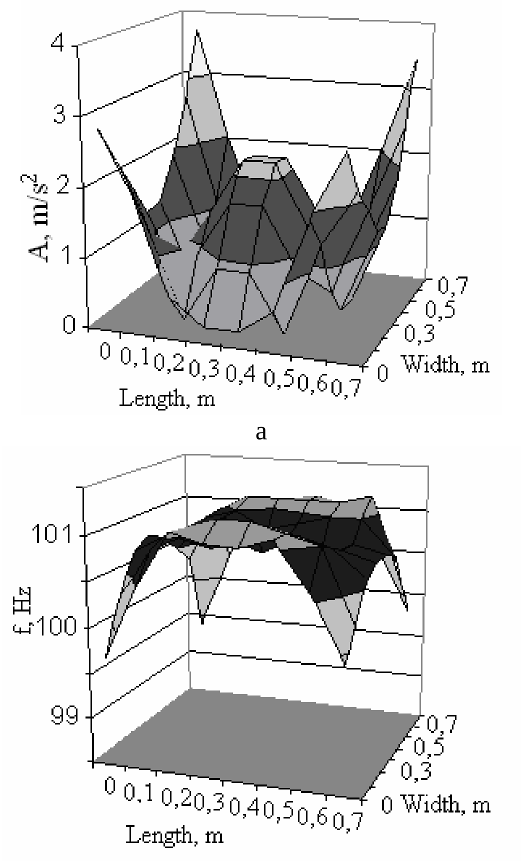


b

Fig. 5. Variation regularities across the grain of transverse oscillations amplitude (a) and the resonant frequency of a wood panel

It was established that in many cases the frequency variation is inversely proportional to the variation of amplitude in different zones of resonant, i.e. frequency value in the zones of maximum amplitude is the lowest and vice versa.

The regularities of variation analogous parameters of a particle board are shown in Fig. 6.



b

Fig. 6. The regularities of variation in oscillations amplitude (a) and the resonant frequency (b) of a particle board in the plane

It was found that in general the regularities of variation in resonant oscillations' amplitude and the frequency of both, glued-up wood panels and particle boards are analogous. In the case of boards, variation of resonant frequency did not exceed 3 %.

Tendency to variation particularly became clear in determining the damping coefficient of assortments, i.e., in evaluating viscous properties.

Values of damping coefficient in the plane of one of the glued-up panels, when it vibrates at frequencies of about 91 Hz and 290 Hz (when the panel bends at the modes akin to the theoretical ones of isotropic beam), are shown in Tables 5 and 6.

Table 5. Values of the damping coefficient of a glued-up panel in the plane of the panel, when it vibrates at the mode across the grain close to the theoretical mode of isotropic beam

p/d		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*	
1	0,0199	9	0,0121	17	0,0242	25	0,0188	33	0,0198	41	0,0188	49	0,0199	57	0,0210
2	0,0188	10	0,0199	18	0,0209	26	0,0209	34	0,0198	42	0,0188	50	0,0221	58	0,0210
3	0,0199	11	0,0210	19	0,0231	27	0,0209	35	0,0209	43	0,0199	51	0,0209	59	0,0199
4	0,0199	12	0,0221	20	0,0198	28	0,0210	36	0,0209	44	0,0221	52	0,0210	60	0,0210
5	0,0210	13	0,0209	21	0,0220	29	0,0198	37	0,0209	45	0,0209	53	0,0220	61	0,0210
6	0,0210	14	0,0210	22	0,0231	30	0,0187	38	0,0209	46	0,0187	54	0,0209	62	0,0210
7	0,0210	15	0,0210	23	0,0221	31	0,0209	39	0,0209	47	0,0198	55	0,0220	63	0,0199
8	0,0210	16	0,0209	24	0,0209	32	0,0209	40	0,0209	48	0,0220	56	0,0187	64	0,0209

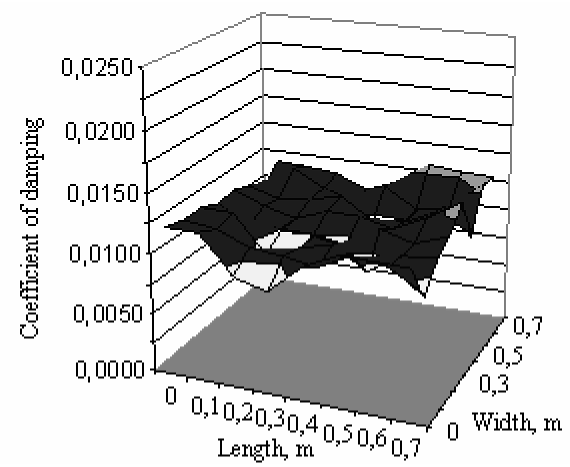
* where *p* – running number of a point; *d* – damping coefficient

Table 6. Values of damping coefficient of particle board in the plane of the board, when it vibrates at mode close to the theoretical mode of isotropic beam

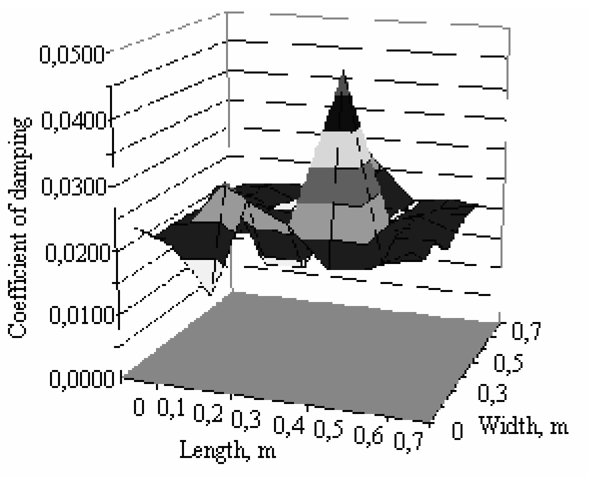
p/d		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*		*p/d*	
1	0,0241	9	0,0219	17	0,0148	25	0,0297	33	0,0267	41	0,0208	49	0,0219	57	0,0250
2	0,0209	10	0,0208	18	0,0307	26	0,0188	34	0,0188	42	0,0485	50	0,0208	58	0,0220
3	0,0209	11	0,0218	19	0,0208	27	0,0218	35	0,0208	43	0,0198	51	0,0228	59	0,0229
4	0,0208	12	0,0228	20	0,0209	28	0,0198	36	0,0198	44	0,0199	52	0,0228	60	0,0199
5	0,0209	13	0,0228	21	0,0218	29	0,0208	37	0,0198	45	0,0209	53	0,0228	61	0,0209
6	0,0229	14	0,0218	22	0,0188	30	0,0208	38	0,0218	46	0,0198	54	0,0218	62	0,0219
7	0,0209	15	0,0218	23	0,0198	31	0,0188	39	0,0198	47	0,0198	55	0,0208	63	0,0220
8	0,0201	16	0,0209	24	0,0208	32	0,0317	40	0,0257	48	0,0198	56	0,0209	64	0,0200

As it can be seen both in particle boards and glued-up panels, damping coefficient is distributed very differently. It was found that the average damping coefficients of these assortments are close to each other. It was determined that the viscous properties of glued-up panels varied in smaller range than those of particle boards (the damping coefficient of glued-up panels and particle boards was 0,019 – 0,022 and 0,015 – 0,045 respectively).

In Fig. 7 the regularities of variation in damping coefficient of glued-up wood panel (a) and particle board (b) in the plane are presented.



a)



b)

Fig. 7. Variation regularities of the damping coefficient of a glued-up wood panel (a) and particle board (b) in the plane

As it can be seen, the laws of variation in the damping coefficient of panels and boards are different. It was determined that the laws of variation of this parameter of separate panels and boards in the plane of assortment are different. It was established that in general case the value of damping coefficient in separate zones of the assortment might vary up to 40 %.

Thus, when evaluating viscous elastic properties of wood articles by the method of resonant oscillations, it is necessary to evaluate the anisotropicity of wood assortments. When determining a dynamic modulus of elasticity and damping coefficient, it is necessary to take into account the law of variation of resonant frequency (as the main measurement parameter) in the plane of assortment. This is particularly important when the method of finite elements is applied, as it allows increasing the correctness of measurement.

Conclusions

1. It was determined that in the analysis of glued-up wooden panels and particle boards as the systems of finite elements, it is necessary to evaluate the degree of their anisotropicity.
2. It was found that the spread of resonant frequency in separate zones of assortments' plane does not exceed 5 %.
3. The noticeable variation of damping coefficient of wood panels and particle boards was determined, i.e., in separate zones of the plane its value may vary up to 40 %.
4. It was established that variation of the main parameters is related to the variation of oscillations' amplitude. Oscillation amplitudes of the separate zones may differ by up to 2.5 times.

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