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Investigation of Wood Mechanical Properties by the Resonance Vibrations Method

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The mechanical properties of wood polymeric system are defined in terms of viscoelastic materials. The response of viscoelastic bodies to external effects depends on the ratio of elastic and viscous properties. These properties have an impact on relaxation processes for both wooden specimens and wooden articles. In this paper the method of estimation of dynamical modulus of elasticity and coefficient of damping based on resonance vibration is presented. Fir timber specimens have been used in the investigation. The specimens were sawn from three places of the log and they were relatively called "but-end" "center" and "top". The highest modulus of elasticity was determined in the specimens from the butt-end of a log, the lowest was in the specimen from the center part. The variation of the coefficient of damping was found to be inversely proportional to that of the value of the modulus of elasticity.

Keywords: dynamical modulus of elasticity, coefficient of damping, resonance vibration, fir timber specimen.

INTRODUCTION

Polymeric materials including wood fall into the category of viscoelastic materials. Their mechanical properties are defined in terms of elastic solids and also of viscous liquids. For this reason, when determining the modulus of elasticity and evaluating the characteristics of viscosity, classical research methods do not provide unambiguous results.

The response of viscoelastic bodies to external effects depends on the ratio of elastic and viscous properties. These properties have an impact on relaxation processes of both wooden specimens and wooden articles. Relaxation processes proceed in time, therefore, stresses and deformations of wood have to be investigated also in the period of time.

To investigate the stress relaxation, a specimen is deformed after which the deformation remains constant, while the stress indispensable for maintaining that deformation reduces with time. In slower straining the stresses manage to relax partly in the deformation conveyance time and the relaxation curve is slightly distorted. The distortions of a relaxation process appear due to insufficient rigidity of a dynomometric device and also due to the ratio of chosen specimens dimensions. In addition, to evaluate the relaxation process completely the investigation should be carried out in the wide interval of temperature, humidity, etc. thus making determination of mechanical properties of polymers possible in a wide range.

The response of viscoelastic material to external effects depends on the period of time. When testing polymers dynamically, the specimen is periodically subjected to loads and the vibrations frequency acts as a time agent. In this way, dynamically testing polymers, in a general case the amplitude of vibrations characterizes the magnitude of stress and the energy dissipation during the cycle of vibrations i.e. damping is evaluated. Then a dynamic modulus of elasticity is evaluated and resonance vibrations suit to this kind of investigation best [1, 2].

A significant part of wooden articles used in airplanes, ship industry undergo dynamic loads. These loads frequently subject building structures, parts of musical instruments, etc. Periodically loading wooden specimens and evaluating their mechanical properties under that regime it is possible to give a complete definition of the behaviour 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, the amplitude versus frequency response characteristic has to be set up for developing the optimal structure of an article. In most cases they must be known in order to avoid resonance phenomena and also either to increase or decrease vibrations damping.

Application of wood is closely connected with its acoustic properties. Then the dynamic modulus of elasticity, and wood density determine absorption and insulation of the sound. In musical instruments, on the contrary, wood is extensively used for sound intensification. In both cases of insulating and intensifying the sound the elastic and viscous properties of wood have to be taken into consideration [3].

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 trunk. Therefore, research in selecting wood for manufacturing the parts of various articles becomes more and more predominant.

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INVESTIGATION PROCEDURE AND EQUIPMENT

In many cases mechanical systems are idealized 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 have been assumed to have no mass.

When the mass of an investigated body is concentrated in “one point” its equivalent mechanical system is simpler. In this case the investigated bar can be simulated by means of a lumped parameter system shown in Fig. 1 [4].

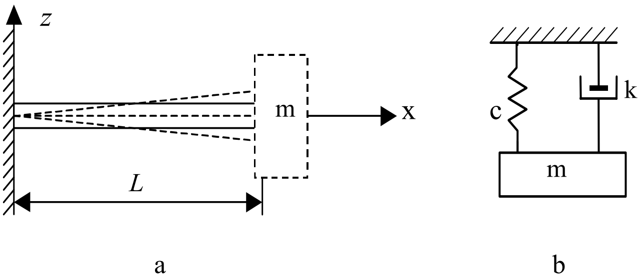


Fig. 1. Scheme of the investigated specimen (a) and its dynamic model (b): *m* is the mass of a specimen; *c*, *k* are the coefficients of rigidity and mean resistance of the specimen, respectively

Equation of that dynamic system may be expressed:

$$m\ddot{z} + k\dot{z} + cz = F \sin \omega t \,. \tag{1}$$

Frequency of the mass free oscillations may be calculated in the following way:

$$\omega = \sqrt{\frac{3EI}{mL^3}}\,, \tag{2}$$

here E is the modulus of elasticity, I is the moment of inertia of the cross-section.

Viscous properties of the investigated bar are evaluated from the curve of resonance vibrations i.e. from the amplitude versus frequency response characteristic.

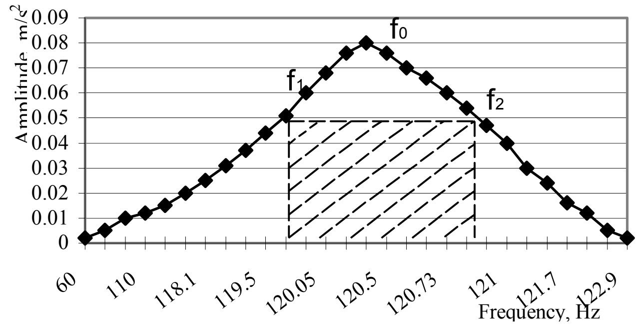


Fig. 2. Amplitude versus frequency response characteristic

Its shape predetermines the internal friction – damping of the specimen. Having resonance frequency f_0 and frequencies band width $\Delta f = f_2 - f_1$, the index of internal friction can be obtained [1]:

$$\frac{1}{Q} \approx tg\delta \approx \frac{\Delta f}{f_0}\,, \tag{3}$$

here $tg\delta$ is the general characteristic of the specimen internal friction – tangent of the losses angle.

The analyzed dynamic system does not fully represent all elastic and viscous wood properties distributed along the bar length when its mass is not concentrated at one of its ends. That bar can be represented by a mechanical system with an infinite number of degrees of freedom. In this case the mass of the bar is also distributed along its length and its transverse oscillations equation can be written as [4]:

$$\frac{\partial^4 z}{\partial x^4} + \frac{\rho S}{EI}\frac{\partial^2 z}{\partial t^2} = 0\,, \tag{4}$$

here ρ is the density of wood, S is the cross-sectional area of the bar.

When solving this equation an infinite sequence of frequencies is obtained. The basic frequency of free vibrations is calculated in the following way:

$$\omega_1 = 3.52\sqrt{\frac{EI}{mL^3}}\,. \tag{5}$$

Viscous properties of the wooden specimen are evaluated analogically to the first case:

$$tg\delta \approx \frac{\Delta f}{f_0}\left(1 - \frac{1}{8}\cdot\frac{\Delta f}{f_0}\right). \tag{6}$$

Since in most rigid bodies including wood $\Delta f / f_0 < 1$, therefore:

$$tg\delta \approx \Delta f / f_0\,, \tag{7}$$

i.e. in this case the viscous properties of the specimen are analogically evaluated.

In addition to the bar-shaped wooden articles there are plate-shaped parts. For their transverse vibrations the analogous fourth power differential equations are set up:

$$\frac{\partial^4 z}{\partial x^4} + 2\frac{\partial^4 z}{\partial x^2 \partial y^2} + \frac{\partial^4 z}{\partial y^4} + \frac{12\rho\left(1-\nu^2\right)}{Eh^2}\frac{\partial^2 z}{\partial t^2} = 0\,, \tag{8}$$

here h is the thickness of the plate, v is the Poisson’s coefficient.

Resonance vibrations of various forms are calculated in the way dependent on the fastening type of plates and bars. When the plate is fastened at its four sides the frequency of the main bending shape is calculated as follows:

$$\omega_1 = 35.99\sqrt{\frac{D}{\rho h a^4}}\,, \tag{9}$$

here $D = \frac{Eh^3}{12\left(1-\nu^2\right)}$, a is the length of the plate.

Viscous properties of the wooden plate can be determined analogically to the bars by investigating any shape of resonance vibrations.

It is obvious that resonance vibrations of bars and plates properly characterize elastic properties of the material they are made of. This procedure is appropriate not only for analysis of separate wooden parts by rendering them the shape of a bar or a plate, it can also be applied to the evaluation of analogous properties of building structures, furniture, musical instruments and other wooden articles. Furthermore, it allows to evaluate the quality of mechanical and glued joints of different articles.

Based on the above-mentioned procedure a testing unit for investigating the properties of wooden specimens has been developed (Fig. 3).

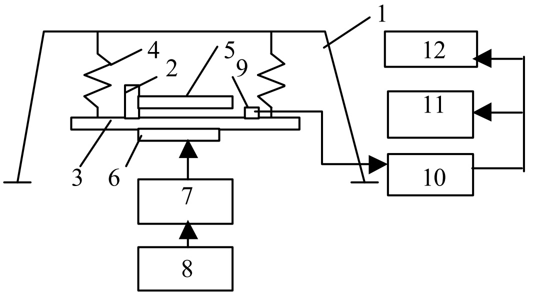


Fig. 3. Testing unit for investigating dynamic parameters of wooden specimens

It consists of frame (1) in which by means of springs (4) platform (3) is hinged. In special block (2) wooden sample (5) is fastened. Below the platform vibrator (6) is fixed which is controlled through amplifier (7) by electric signals generator (8). The vibrations of the platform excited by the vibrator are recorded by a transducer (9) fixed on the platform. Varying the generator frequency the resonance vibrations of the specimen are recorded, their amplitude is measured by measuring device (10), and their frequency is determined by a cymometer (11). The vibrations shape is observed on the screen of oscillograph (12) [5].

EXPERIMENTAL DATA

Fir timber specimens have been used in the investigation. In the initial stage they were optionally chosen i.e. they were sawn from different places of the stem. The specimen dimensions (400 × 40 × 14 mm) were measured by a rule (0.1 mm accuracy), by vernier calliper (0.01 mm accuracy) and they were weighed by electronic scales (0.001 g accuracy). Wetness of the specimens was determined by a hydrometer. The dynamic modulus of elasticity and damping of wood were evaluated by referring to (5) and (7) expressions.

The data of measurements and calculations are given in Table 1.

Table 1. Measurements and calculations data

Specimen Nr.	f_0	f_1	f_2	$\Delta f = f_2 - f_1$	E, MPa	$1/Q$
1	120.3	119.9	120.73	0.83	9896.771	0.006899
2	97.8	97.46	98.21	0.75	15979.61	0.007669
3	69.4	69.21	69.6	0.39	21915.61	0.005620
4	172.4	171.7	172.92	1.22	13685.59	0.007077
5	121.1	120.68	121.58	0.9	12254.31	0.007432
6	116.2	115.8	116.57	0.77	11398.18	0.006627
7	67.5	67.35	67.71	0.36	15780.24	0.005333

The presented data indicate that the mean modulus of elasticity of the analyzed specimens is $E = 1.44 \cdot 10^4$ MPa. When compared with the data given in References (for fir timber – $1 \cdot 10^4 - 1.5 \cdot 10^4$ MPa) we see these results agree with the practically obtained ones. Wood damping is evaluated by applying the amplitude versus frequency response characteristics of the specimens (Fig. 4).

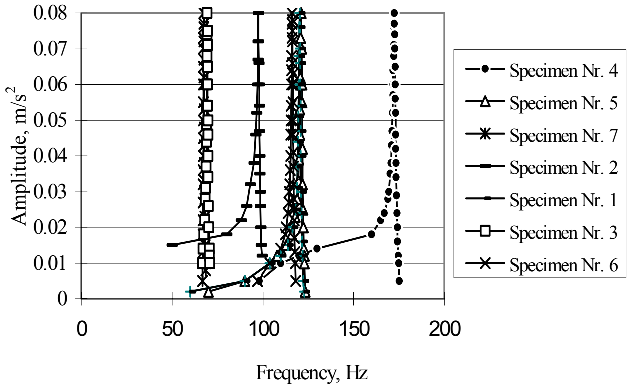


Fig. 4. Amplitude versus frequency response characteristics of the specimens

When analyzing the investigated specimens it has been found that due to the different wood structure in various places of the stem, sawing direction, defects, etc. both the modulus of elasticity and the coefficient of damping vary in the wide range. The variations of these parameters are related not merely to the different wood structure but to the sawing direction, defects, branches and the other.

Since relatively small specimens can be used for testing, this procedure makes it possible to investigate wood properties in various places of the stem. A log of a six meter fir was taken for investigation purposes. Its diameter in the butt-end was 0.4 m, and its taper – 0.8 cm/m. The specimens were sawn from three places of the log and they were relatively called “butt-end”, “center” and “top”. The sawing scheme of the log and its butt-end is given in Fig. 5.

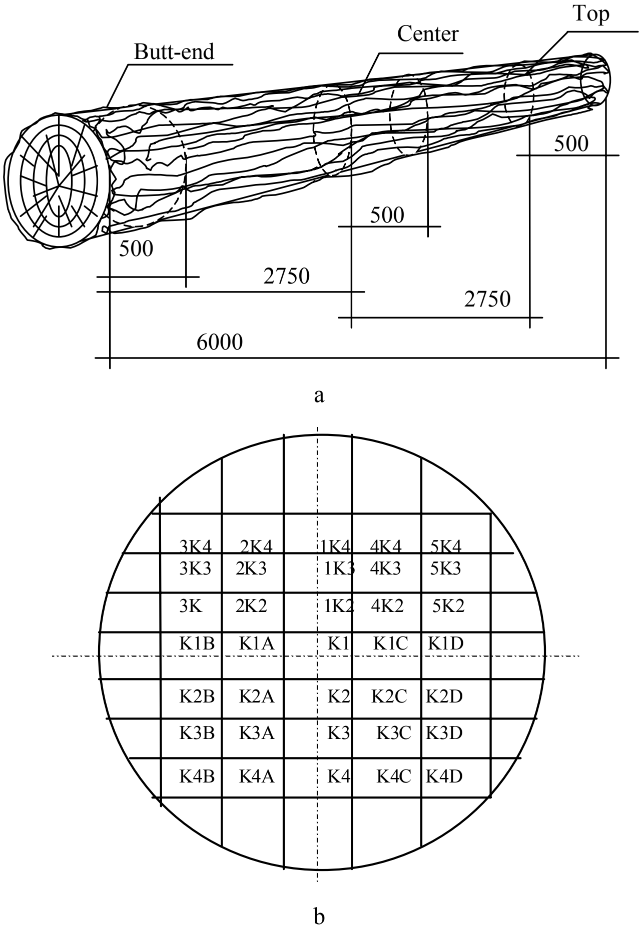
The center and the top were sawn analogically to the butt-end. That way of sawing of the log parts enables to determine the variation of the dynamic modulus of elasticity and damping not merely along the length of the log but in its different layers and in the directions of rings arrangement.

Fig. 6 illustrates the distribution of these parameters in the length of the log taking into consideration the mean modulus of elasticity and coefficient of damping in certain points of the log.

Testing the external specimens of the log (Fig. 7) the dependence of the dynamic modulus of elasticity and damping on the fibre direction and number of rings was obtained. In these specimens the tangential and closer fibre direction predominates. There the number of rings and their width in the specimen have a significant effect on the value of the measured parameters.

The lower points of the graphs are: in the butt-end K4 and K4A specimens (ring width reaches 7.5 mm), in the center – S1D and S2D (ring width is 6 mm) and in the top 2V4 and 2V3 (ring width is 4 – 5 mm).

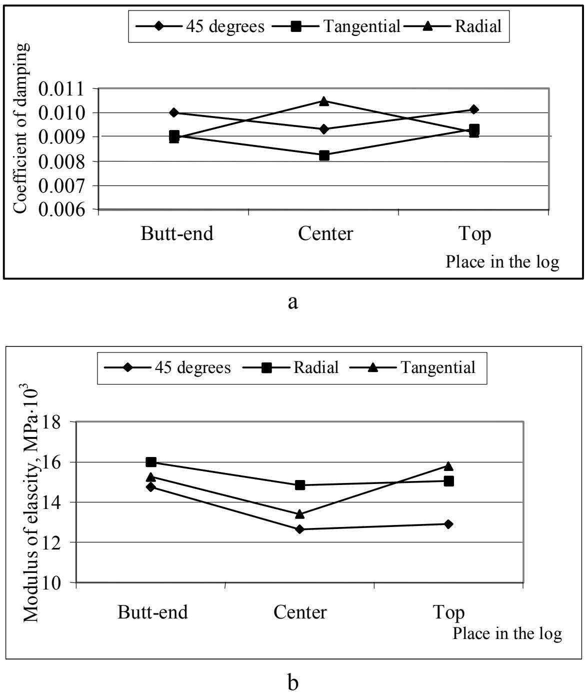
It is evident that the highest modulus of elasticity ($1.45 \cdot 10^4 - 1.6 \cdot 10^4$ MPa) is at the butt-end of the log.



a

b

Fig. 5. Sawing scheme of log (a) and its butt-end (b)



a

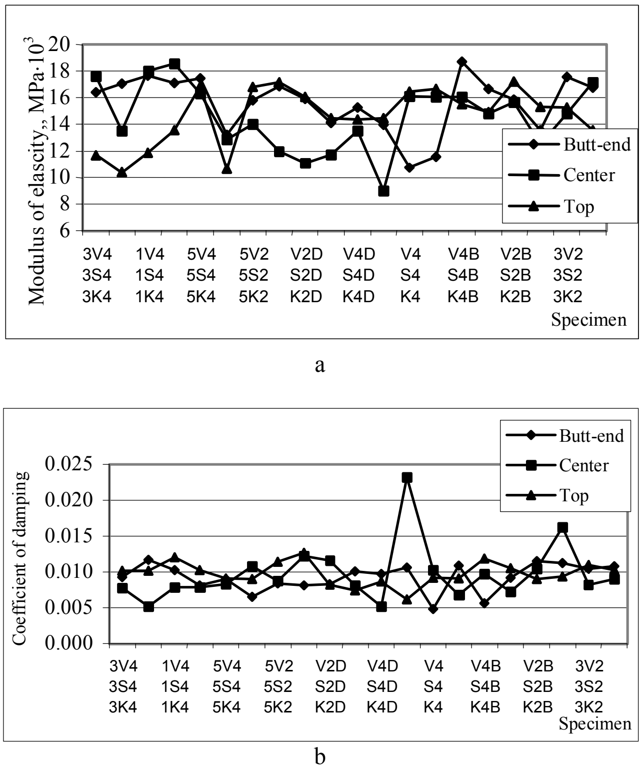
b

Fig. 6. Graph of the dependence of the dynamic modulus of elasticity (a) and the coefficient of damping distribution along the length of the log on variation of a fibre direction

Towards the center the value of the modulus of elasticity decreases, whereas, towards the top it negligibly increases. It is due to the change of wood density (in the butt-end it is of 438.5, in the center it is of 425.7 and in the top it is of 432.4 kg/m^3). In the top zone the branchiness increases thus causing the increase in wood density. The variation of this parameter slightly depends on the fibre direction in a specimen.

The variation of the coefficient of damping along the length of the log corresponds to the elastic-plastic properties of material i.e. the elastic properties are replaced by the viscous ones. In this case the value of the coefficient of damping was affected by wood humidity (in the butt-end it reached 19 %, in the center it was 10 % and in the top 18 %).

Comparison of the highest graph points has indicated that in these places the radial fibre direction prevails while the width of rings is the smallest: (in the butt-end – specimens 5K4, 3K2, ring width 2 mm, in the center is 1S4, 4S4 is 2 mm, in the top is 5V4, V2B is 2 mm). In some specimens (K4C, S4, S4A) the values of the modulus of elasticity noticeably change because of various defects present in them.



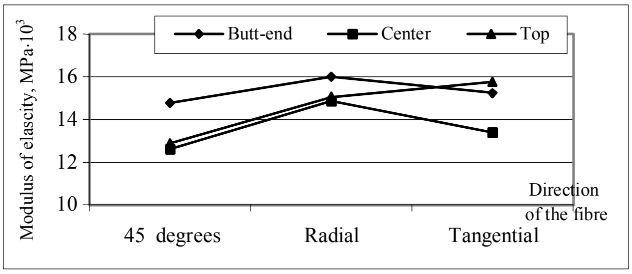
a

b

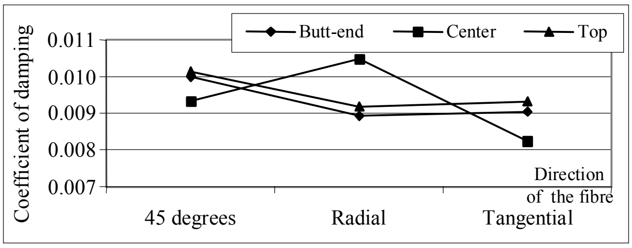
Fig. 7. Variation laws of the dynamic modulus of elasticity (a) and the coefficient of damping (b) along the external specimens of the log

In many places the variation of the coefficient of damping along the external specimens of the log corresponds to the properties of viscoelastic materials namely, with an increase in the modulus of elasticity the coefficient of damping decreases. The defects in the specimens have an important bearing on this parameter variation in analogical cases of the modulus of elasticity.

Analysing the effect of the fibre direction (Fig. 8) the lowest value of the modulus of elasticity was found to exist when the fibre direction forms 45 angle with that of the specimen bending, whereas the highest value is at the radial direction of fibres.



a



b

Fig. 8. Distribution laws of the dynamic modulus of elasticity (a) and the coefficient of damping (b) according to the fibre direction

Actually, the variation of the coefficient of damping is inversely proportional to that of the value of the modulus of elasticity. In this and former cases the regularities of the above-mentioned parameters variation have been distorted by some flaws as branches, splits, etc.

Therefore, in order to use wood for manufacturing various purpose parts the properties of wood as viscoelastic material have to be considered in different places of the log.

CONCLUSIONS

1. Conventional and complex dynamic models of a specimen can be applied for evaluating elastic and plastic properties of wood.
2. Applying different models of a specimen the trend toward variation of dynamic parameters remains the same except the value of the modulus of elasticity (differs about twice).
3. 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.
4. The highest modulus of elasticity was determined to exist in the specimens from the butt-end of a log, the lowest was in the specimens from the center part.
5. The variation of the coefficient of damping was found to be inversely proportional to that of the value of the modulus of elasticity.

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