Experimental Investigations of Wood Damping and Elastic Modulus

Maria CIORNEI, Emanuel DIACONESCU, Marilena GLOVNEA
Universitatea „Ștefan cel Mare”
Suceava, România
maryac_c@yahoo.com, emdl@fim.usv.ro, mglovnea@yahoo.com

Rezumat: Capacitatea de amortizare și modulul de elasticitate sunt parametrii cei mai importanti care caracterizează proprietățile mecanice ale lemnului. Lucrarea își propune determinarea experimentală a factorului de amortizare, studiind micșorarea amplitudinilor în vibrațiile libere ale unor epruvete din zece esențe diferite de lemn. Vibrațiile amortizate sunt transmise prin intermediul unui traductor piezoelectric la un osciloscop cu memorie și apoi transferate unui P.C. (Personal Computer), care permite interpretarea datelor și transferul graficelor în Word. Decrementul logaritmic al acestora este o măsură a amortizării interne a lemnului, iar frecvența de oscilație permite determinarea constantei elastice a barei și de aici a modului de elasticitate.

Abstract: The damping capacity and the elastic modulus are the most important parameters to characterize wood’s mechanical properties. This paper deals with a simple experimental technique for determination of the wood damping factor by measuring the amplitude decrement of free vibrations in probes made of ten wood essences. Damped vibrations are captured by aid of a piezoelectric transducer and transferred to a storage oscilloscope. Then, they are uploaded to a computer, which allows data interpretation and transferring the graphs to a text editor. The logarithmic decrement is an indicator of internal damping in wood, and the oscillating frequency allows determining the elastic constant of the probe and thus the longitudinal elastic modulus.

Keywords: Free vibrations, damping factor, logarithmic decrement, elastic modulus.

1. Introduction

By definition, damping is associated with energy dissipation in a material or a system under cyclical loading. In most cases, mechanical energy is transformed in heat. The research on internal damping aims to check different hypotheses on the molecular structure of crystalline materials and polymers. Also, the damping capacity of different materials was used as an important property in the analysis of the structural and acoustic properties (the determination of the dynamic response and the behavior to fatigue by resonance). Measurement of material damping has long been a popular activity among experimental physicists, dating back to 1837 [1]. Almost all descriptions of damping are derived from the linear single degree of freedom system with a viscous damper in parallel with a spring, as follows:
(a) Logarithmic decrement [2] – the decay rate definition of damping may be based on the concept of energy dissipation per cycle of vibration. If this energy loss is small compared to the stored energy, the amplitude will not decrease very much in one cycle of free vibration and the motion is very close to being sinusoidal. For a single degree of freedom system, or one that is vibrating in a single mode shape, the frequency is a determined quantity and the energy loss per cycle is a function only of amplitude or stress level;
(b) Amplification factor [3] – in a linear single degree of freedom system, if a constant sinusoidal excitation force is applied with gradually increasing frequency, it will be found that the amplitude of vibration steadily increases to a maximum and then decreases as the frequency is further increased;
(c) Equivalent dashpot constant [4];
(d) Quality factor [5] – of a system is defined in terms of the ratio of dissipated energy to the stored energy;
(f) Bandwidth [8] – based upon the difference in the two frequencies at which the amplitude is the same if the exciting force is the same.

This paper presents a simple technique for experimental determination of the damping factor and the elastic modulus of various wood specimens. The logarithmic decrement is an indicator of internal damping in wood, and the oscillating frequency allows determining the elastic constant of the probe and thus the elastic modulus.

The elastic modulus, determined by this procedure falls between $0.957 \times 10^8$ and $3.987 \times 10^8$, which is similar to previous experiments [9], based on measurement of elastic deflections.

2. Damping of free vibrations

Free vibrations that can maintain the same amplitude indefinitely don’t exist in nature. Amplitudes continuously decrease due to friction in the oscillating system. This means that free vibrations suffer damping. Such motion is no longer a periodic one, but is none the less considered a vibratory movement. As friction occurs between the oscillating system and the environment or internally in the system, the damping can be external or internal.

External damping is characterized by the existence in the system of resistant forces, applied to the moving mass. Unlike the external one, the internal damping is characterized by a change of the hysteresis loop in the loading – unloading diagram of the elastic element. The area closed by the hysteresis loop is proportional to the dissipated energy during a loading – unloading cycle.

Complex studies of the damping phenomena show that different mathematical laws can be used to approximate the resistant force or the dissipated energy. Thus, for the external damping, the most commonly used laws are: the viscous friction force, proportional to the relative velocity and the dry friction force, which is constant during a half-period.

As far as the internal damping is concerned, based on experimental investigations, materials can be classified in two categories: materials for which the damping is dependant on both amplitude and frequency, and materials for which damping depend on only the amplitude (hysteretic damping).

The law governing a damped vibration has the following form:

$$x = x_0 \cdot \exp(-ht) \cdot \cos(\omega t + \varphi),$$

where $h$ is called damping factor. The amplitude is a function of time and it decreases towards zero. The damped vibration is quasi-harmonic (pseudo-periodic) exponentially modulated in amplitude, and the period is called a pseudo-period. Speed and acceleration also decrease in time.

**Fig. 1.** Damping of free vibrations [10].

The diagram of a damped vibration (Figure 1) is situated between two exponential laws of the following form [10]:

$$x = \pm x_0 \cdot \exp(-ht),$$

In order to determine the elastic modulus $E$, also known as Young modulus, the logarithmic decrement $\delta$, and the damping factor $h$ respectively, the following equations can be used:

$$E = \frac{4\pi^2 f^2 ml^3}{3I_z},$$

$$\delta = \ln \frac{x_n}{x_{n+1}},$$

$$h = \frac{\delta}{T},$$

where: $f = \frac{1}{T}$ - frequency, $m$ - mass, $l$ - probe length, $I$ - inertia moment, and $T$ – the motion period.
3. Experimental set-up

This paper presents the experimental setup for measuring the damping factor (logarithmic decrement) as well as the elastic modulus of wood. To this end, a simple device has been conceived and built. The experimental device allows a rapid determination of the two parameters for wood specimens having a rectangular transversal profile and a length of 240 mm. The experimental set-up, shown in Figure 2, is composed of a Tektronix TDS300 series storage oscilloscope, a piezoelectric transducer used to measure vibrations, the mounting device for the probes and a computer [11].

![Experimental set-up](image1)

**Fig. 2.** Experimental set-up.

The mounting device (Figure 3) consists of a base and a vertical bar [11]. On the bar, a specimen holder can be set at different heights. The specimen holder has a horizontal slot, in which the probe can be fixed in position.

For the proposed experimental investigations, wood specimens having a rectangular transversal profile of either 19 mm × 5 mm or 19mm × 6 mm and a length of 240 mm (see Figure 4) were used. The specimens were made of various wood species, namely oak, deal, birch, beech, plank, lime-wood, bird cherry, sycamore maple, hornbeam and field maple.

The transducer is fixed in a hole positioned at 10 mm from the free end of the specimen.

![Mounting device](image2)

**Fig. 3.** Mounting device.

![Wood specimens](image3)

**Fig. 4.** Wood specimens having a rectangular transversal profile of either 19 mm × 5 mm or 19mm × 6 mm and a length of 240 mm.

4. Experimental investigations

The first step in the experimental investigations is to calibrate the assembly piezoelectric-transducer - storage oscilloscope. Then, the wood specimen is positioned in the mounting slot and fixed using two screws. On the free side of the specimen, at 10 mm from the end, the piezoelectric transducer is fixed and its output is connected to the X input of the storage oscilloscope.
A mechanical initial pulse is applied to the free end of the specimen so that to cause a given initial deflection of 2 – 4 mm. Then, the specimen end is suddenly released. The damped free vibration of the specimen can be visualized on the storage oscilloscope (see Figure 5) and uploaded to a computer, using the WaveStro software.

**Fig. 5.** Visualization of free vibrations damping on the storage oscilloscope.

Two tests were performed for each specimen at imposed vertical bending deflections ranging between 1 and 4 mm.

5. Experimental results

Typical waveforms obtained for deal specimen at an initial bending deflection of 3 mm and hornbeam at an initial bending deflection of 2 mm, are illustrated in Figures 6.a and 6.b, respectively.

Table 1 synthesizes the results obtained by using equations (3). It can be noticed that, as far as the internal damping capacity is concerned, the different types of wood can be classified as follows: \( \delta_{\text{lime-wood}} = 0.234; \ \delta_{\text{birch}} = 0.223; \ \delta_{\text{beech}} = 0.194; \ \delta_{\text{field maple}} = 0.167; \ \delta_{\text{bird-cherry}} = 0.154; \ \delta_{\text{hornbeam}} = 0.134; \ \delta_{\text{oak}} = 0.105; \ \delta_{\text{aspen-maple}} = 0.105; \ \delta_{\text{oak}} = 0.105; \ \delta_{\text{deal}} = 0.083; \ \delta_{\text{plank}} = 0.061. \)

**Fig. 6.** Vibration damping; a – deal at an initial deflection of 3 mm; b – hornbeam at an initial deflection of 2 mm.

The elastic modulus, determined using this procedure, falls between \( 0.957 \times 10^6 \) and \( 3.987 \times 10^6 \), which is similar to previous experimental results reported in reference [9]. These were obtained by using elastic deflection measurement.
### Table 1. Experimental results [11].

<table>
<thead>
<tr>
<th>Wood</th>
<th>Deflection, v [mm]</th>
<th>Elasticity modulus, E [Pa]</th>
<th>Frequency, f [Hz]</th>
<th>Logarithmic decrement, δ</th>
<th>Damping factor, h [Hz]</th>
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</table>

### 6. Conclusions

Damping capacity and elasticity modulus are two important parameters that characterize the mechanical properties of wood. These parameters are usually measured by aid of relatively complex devices.

In order to experimentally determine these two parameters, a simple device that uses parallelepiped wood specimens was conceived and built. The probe is fixed at one end, and a piezoelectric accelerometer is placed at the other.

If the system equilibrium is broken by an impulse on the free end of the probe, followed by a quick release, damped free vibrations appear. The logarithmic decrement of these vibrations is an indicator for internal damping in wood, whereas the oscillating frequency allows determining the elastic constant of the specimen and therefore the elastic modulus.

As far as the internal damping capacity is concerned, different types of wood can be classified as follows: δ_{lime-wood} = 0,234; δ_{birch} = 0,223; δ_{beech} = 0,194; δ_{field maple} = 0,167; δ_{bird-cherry} = 0,154; δ_{hornbeam} = 0,134; δ_{sycamore maple} = 0,105; δ_{oak} = 0,105; δ_{deal} = 0,083; δ_{plank} = 0,061.

The elastic modulus, determined using this procedure, falls between 0,957×10^8 and 3,987×10^8, which is similar to previous experimentally obtained values.

The experimental method can be improved by adding a supplementary weight on the free end of the specimen, thus eliminating the effect of its own mass on the vibratory regime.

### References


Drd. ing. Maria CIORNEI
Universitatea „Ștefan cel Mare”, Suceava, Facultatea de Inginerie Mecanică, specializarea Inginerie Mecanică, absolventă a Facultăţii de Inginerie Mecanică, preocupări ştiinţifice în domeniul Ingineriei Mecanice, conducător ştiinţific - prof. univ. dr. ing. Emanuel Diaconescu, teza de doctorat în domeniul Ingineriei Mecanice.