A görbék futásából megállapítható, hogy egyazon szín előállítása különböző hőmérsékleteken csak 100 °C környékén valósítható meg. A lényegesen alacsonyabb vagy magasabb hőmérsékleteken a tendenciák jelentősen eltérnek. Hasonló eredményre jutnánk, ha az a*-L* koordináta rendszerben ábrázolnánk a színpontokat.

Összefoglalás

Széles hőmérséklettartományt megvizsgálva megállapítottuk, hogy a színváltozás erősen függ a hőmérséklettől és a gőzölés idejétől. Ezért a gőzölő berendezés hőmérsékletének konstans hőmérsékleten tartására nagy figyelmet kell fordítani.

A gőzölés során az akác faanyag kedvezőtlen zöldes-sárga színe esztétikus, barnás árnyalatúvá változik, és csökken a színbeli inhomogenitás is. Az akác alapszínétől egészen a csokoládébarna színig szinte valamennyi barnás árnyalat előállítható a gőzölési paraméterek megfelelő megválasztásával.

A sötétebb árnyalatok eléréséhez magasabb hőmérséklet javasolt; itt viszont a vörös árnyalatok egy része nem érhető el. A 95 °C alatti hőmérsékleten viszont szélesebb színezeti skála valósítható meg mérsékelt színbeli sötétedés mellett, de hosszú gőzölési idővel.

A vizsgált hőmérséklet-tartományban 6 napnál tovább nem érdemes az akác faanyagot gőzölni. A hőmérséklet növekedésével ez az időtartam rövidül, 130 °C-on fél napra zsugorodik.

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Nondestructive Testing of Wood - A new course offered by the University of West Hungary, Sopron

Ferenc Divos [❖]

Roncsolásmentes faanyagvizsgálat – új tantárgy a Nyugat-Magyarországi Egyetemen

A roncsolásmentes anyagvizsgálat egyre fontosabb szerepet kap a faiparon belül. Példaként említhetjük a szerkezeti faanyagok szilárdság szerinti osztályozását, a rönkosztályozást, a próbaterhelést, az ultrahangos furnérvizsgálatokat. A Nyugat-Magyarországi Egyetem hallgatói külön tantárgy keretein belül ismerkedhetnek a témakörrel. Mivel a roncsolásmentes vizsgálat igen gyakorlati dolog, a laboratóriumi gyakorlatok az oktatás fontos részét képezik. Cikkünkben ismertetjük néhány ilyen laboratóriumi kísérlet leírását is.

Key words: Nondestructive testing, Practical training, Vibration testing

Introduction

Nondestructive testing (NDT) plays a more and more important role in the forest products industry. A few examples are strength grading of structural lumber, log sorting, proof loading, ultrasonic veneer grading and on-line ultrasonic particle board evaluation.

[❖] Dr. Divós Ferenc CSc. egy. docens, NyME Roncsolásmentes Faanyagvizsgálati Laboratórium

At the University of West Hungary, an independent course deals with wood NDT, whose basis was a systematic research work on nondestructive testing of wood that started in 1989. This paper presents the short content of this course. Because NDT is very much practice oriented, laboratory practice is an important part of the education. This paper also presents the description of some compulsory laboratory sessions like dynamic MOE determination by longitudinal and transverse vibration using Euler and Timoshenko equations, and shear modulus determination.

The structure of the course

Non-destructive testing of wood is a fairly new discipline. It offers a great opportunity to demonstrate the practical importance of mathemathics and mechanics for students through FFT, radon transform, vibration of beams and proof loading, where the applications are taken from the forest products industry. We provide the structure of the theoretical lectures and practical training in keyword form. One semester consists of 13 weeks of classes. In the first half of the semester (6 sessions) there are two-hour lectures each week, followed by seven laboratory sessions in the second half.

The course includes the following lecture topics:

- Stress grading of structural lumber
- Proof loading
- Screw withdrawal resistance, correlation with sear modulus and density
- Detecting vibrations by microphone and accelerometers
- Damped and undamped vibration, damping and logarithmic decrement
- Evaluation of vibration by Fourier transformation and wavelet analysis
- Longitudinal, transverse and torsional vibration of prismatic beams,
- Inverse radon transformation and back-projection as the basis of tomography evaluation
- Acoustic tomography and CT
- Gamma ray interactions with solids
- Thermography for surface density determination and internal cavity detection.

NDT is very much practice oriented, and laboratory training is an important part of the education. **Figure 1** shows two such training sessions, where students assess screw withdrawal in a roof structure, and use acoustic tomography.

The structure of the laboratory practice is given as follows:

- Evaluation of trees, detecting internal cavities by acoustic tomography
- Stress grading of structural lumber
- Evaluation of the residual strength of the beams in historical wooden structures
- Selecting wood for musical instruments based on sound velocity, density and damping
- Stress wave propagation mapping in wood
- Shear modulus determination using the Timoshenko equation and torsional vibrations

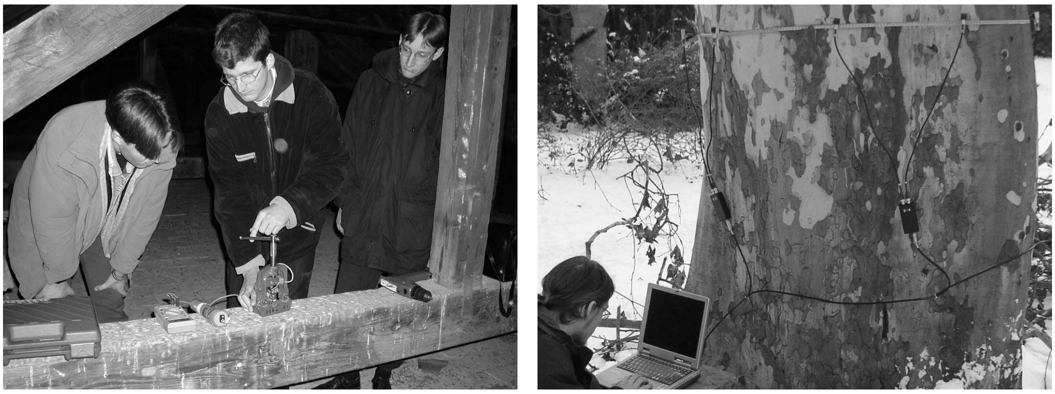

Figure 1 – Laboratory sessions. Students are testing a roof structure by a screw withdrawal resistance meter and evaluate a plane tree by an acoustic tomograph in winter.

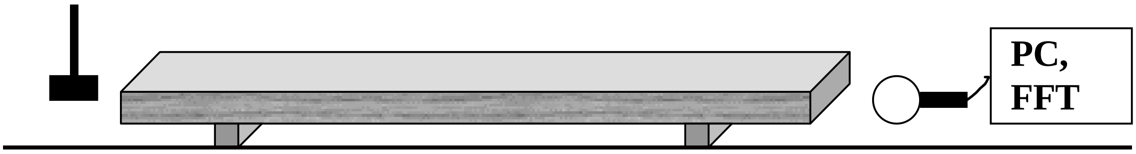

Figure 2 – longitudinal MOE determination

- Modulus of elasticity (MOE) determination by longitudinal and transverse vibration
- Density determination by gamma absorbtion using Am-241 isotope

A description of some laboratory sessions

The brief description of a few lab sessions is presented below. All of them are based on the vibration of a prismatic bar. The necessary tools are a scale balance and an FFT analyzer.

A PC containing a standard sound card may be transformed into an FFT analyzer using a special software. A free copy of this software is available per request from the author (divos@fmk.nyme.hu).

The features of the FFT software are:

- The frequency range is 0 to 11 kHz, adjustable in 10 steps.
- Musical tuning function: a blue bar shows the deviation from the nearest clear tone.
- Normal A tone frequency is adjustable. The preset value is 442 Hz
- The program displays the tallest peak parameter and the tallest peak around the mouse position.
- 512 point FFT and a special averaging function yield low frequency determination error (less than 0,1% of the selected range.)
- Transient recording by the trigger function is possible.
- Hold function facilitates the detailed evaluation.
- Horizontal scale adjustment is possible.

Modulus of elasticity determination on prismatic bars, using longitudinal vibration

The following equation yields the dynamic longitudinal modulus of elasticity (MOE) of homogeneous prismatic bars:

$$MOE_{dyn,long} = \rho V^2, \qquad [1]$$

where ρ is the density of the bar and V is the sound velocity. A precise sound velocity determination is given by longitudinal vibration, as follows:

$$V = 2Lf, \qquad [2]$$

where L is the length of the beams and f is the longitudinal vibration frequency.

The measurement may be carried out on any solid material. The recommended length is minimum 0.5 m or a minimum 5 times the width of the bar, whichever is longer. One can test shorter beams, but a high frequency response microphone, such as a dynamic microphone, is required. In this case, the minimum length can be reduced to 0.3 m.

Figure 2 shows the test setup used for stress-wave MOE determination. The test bar is supported by two rubber strips. The end of the bar is hit by a hammer, while a microphone picks up the vibration signal at the opposite end. The direction of the strike should be longitudinal. The hammer should weigh 0.5 to 5% of the specimen's mass. The hammer head is made of steel or a dense hardwood. A perfect hit is swift and the hammer springs back from the bar.

FFT software settings to be used: the frequency range is 11025 (or 5512) Hz and the trigger level 5%, but in a noisy environment higher trigger levels are recommended.

Typically more than one peak is observed. For selecting the longitudinal vibration frequency, one need to predict the longitudinal frequency of dry wood samples using the following term:

$$f = 2500 / L, \qquad [3]$$

where the L is the length in m and the predicted frequency is given in Hz. The actual frequency

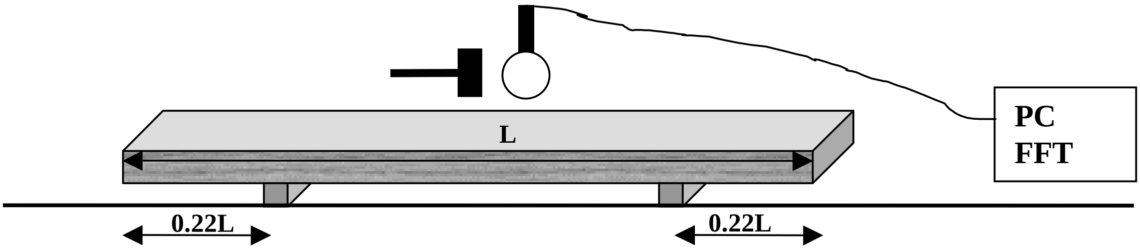

Figure 3 – transverse MOE determination

will be in the range of the predicted frequency ± 20 %. For wet wood samples, use 1600 instead of 2500.

The equipment needed for the test is a scale balance, measuring tape and/or caliper, rubber strips, a hard hammer, the specimens and a PC with a sound card, microphone and FFT software.

Modulus of elasticity determination on prismatic bars, using transverse vibration

The dynamic bending modulus of elasticity (MOE) of homogeneous prismatic bars is given by the following term, where the effect of the shear is neglected:

$$MOE_{dyn,bending} = \left(\frac{2 f_n}{\gamma_n \pi}\right)^2 \frac{mL^3}{I}, \qquad [4]$$

where:

f_n - bending vibration frequency in mode number n (support condition simply supported)

γ_n - mode coefficient; $\gamma_n = (n+0.5)^2$, where n is the mode number, but $\gamma_1 = 2.267$

m - the mass of the bar

L - the length of the bar

I - moment of inertia; $I = \frac{ab^3}{12}$ where a is the width and b is the depth of the bar.

The effect of shear is negligible if the length of the bar is higher than 30 times of the thickness. When the specimen is shorter, the obtained result is lower than the correct value. A more accurate solution is provided by the Timoshenko equation. Another lab session deals with this problem.

The measurement may be carried out on any solid material. The recommended length is at least 30 times of the thickness of the bar. Using a slender beam is recommended.

Figure 3 shows the test setup used for dynamic bending MOE determination. The test bar is supported by two rubber strips. In this case, the center of the bar is hit by a hammer. The hammer should weigh 0.5 to 5% of the specimen's mass. The hammer head is made of rubber or some other soft material.

FFT software settings to be used: the frequency range is 1102 Hz and the trigger level 5%, but in a noisy environment higher trigger levels are recommended.

The tallest peak observed on the Fourier spectrum belongs to the bending vibration in mode number 1. For testing higher modes, rubber supports should be placed at the appropriate nodal points as indicated on **Figure 4**, and the maximum amplitude locations should be the hit and microphone locations.

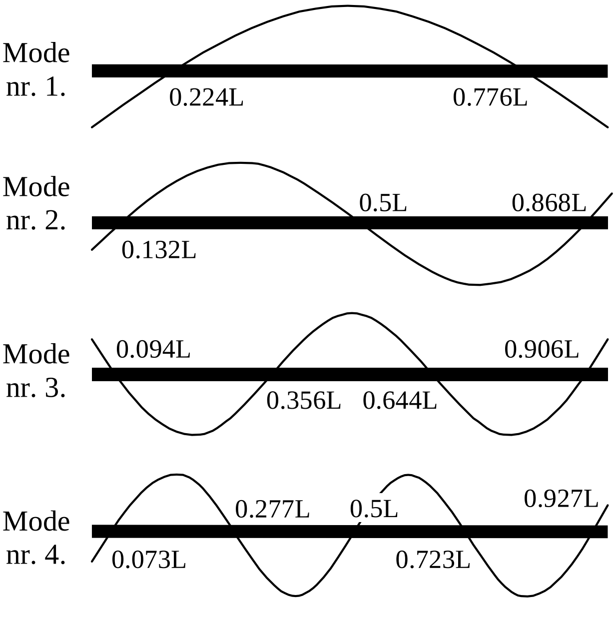

Figure 4 – Nodal locations for the free bending vibration of a uniform cross section bar, free support conditions

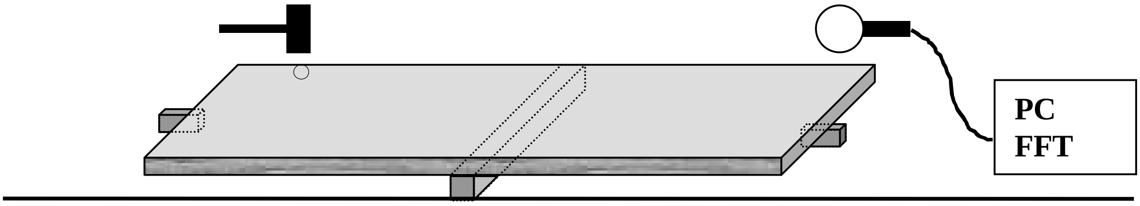

Figure 5 – transverse MOE determination

The equipment needed for the test is a scale balance, measuring tape and/or caliper, rubber strips, a soft hammer, the specimens and a PC with a sound card, microphone and FFT software.

Determination of the shear modulus of prismatic bars by torsional vibration

The dynamic shear modulus (G) of homogeneous prismatic bars is given by the following equation:

$$G_{dyn,torsion} = \left(\frac{2Lf_n}{n}\right)^2 \frac{\rho I_p}{K_t}, \qquad [5]$$

where

f_n - torsional vibration frequency in mode number n,

γ_n - mode coefficient (as given at equation [4])

ρ - the density of the bar

L - the length of the bar

I_p - polar moment of inertia $I = \frac{ab}{12}\left(a^2 + b^2\right)$ where a and b are the cross-sectional dimensions,

$K_t = cab^3$ where $a \geq b$, and c is as given in the **Table 1**.

Table 1 – the values of parameter *c*

a/b	***c***	***a/b***	***c***
1	0.141	3	0.263
1.25	0.172	4	0.281
1.5	0.196	5	0.291
1.75	0.214	10	0.312
2	0.229	20	0.323
2.5	0.249		

Figure 5 shows the test setup used for dynamic shear modulus determination. The test bar is supported by a rubber strip at the center of the bar and two small rubber supports are placed at the ends according to the figure. The specimen is hit at the location marked by a circle, close to the corner. The microphone's location is at the diagonally opposite corner. The hammer should weigh 0.5 to 5% of the specimen's mass. Soft and hard hammers are used for low and higher frequencies, respectively.

FFT software settings to be used: the frequency range depends on the dimensions, and the trigger level 5%, but in a noisy environment higher trigger levels are recommended.

The identification of torsional peaks is not easy. Bending and torsional peaks typically appear together (**Figure 6**). The bending frequencies should first be determinded and excluded from the determination. The remaining ones are the torsional peaks. Torsional peaks are almost equidistant; the ratio between modes 1, 2 and 3 are 1, 2 and 3, respectively. In practice, a ± 10 % deviation is possible.

The equipment needed for the test is a scale balance, measuring tape and/or caliper, rubber strips, a soft or a hard hammer, the specimens and a PC with a sound card, microphone and FFT software.

Conclusions

The newly introduced Nondestructive Testing of Wood is a successful, practice oriented course. Students are introduced to the concept of nondestructive testing through a series of lectures and laboratory sessions that are designed to keep them alert. This paper

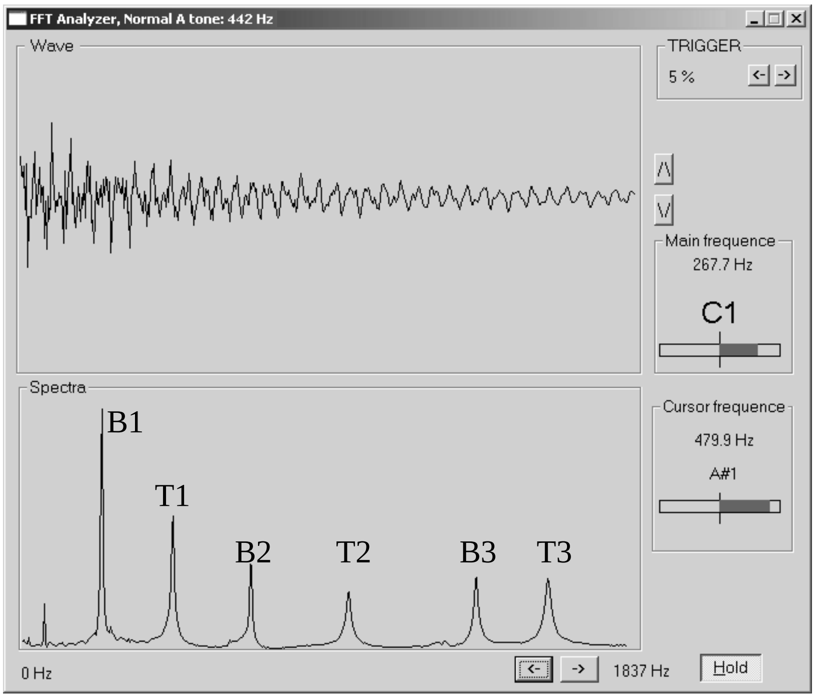

Figure 6 – Sample spectrum along with the Fourier function. Bending (B1, B2 and B3) and torsional (T1, T2 and T3) vibration peaks are indicated.

demonstrates how simple tools may be used effectively to provide an interesting, practical introduction to the topic of nondestructive testing of wood.

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A kettős hangzás előrejelzése és vizsgálata xylofon készítésekor

Taschner Róbert

Predicting and investigating double resonance during xylophone manufacture

Double resonance effect is a problem when manufacturing percussion instruments like xylophone or marimba. Bending and torsional vibrations are both present when hitting a tone bar. When these two vibration frequencies are close to one another, double resonance occurs that significantly deteriorates the quality of the instrument. The author presents a simple method for predicting the likelihood of double resonance in a material of a certain length, and verifies the accuracy of the method through experimental results. The efficiency of the method is also demonstrated by a top quality xylophone manufactured from black locust wood.

Key words: Black Locust, Xylophone, Double resonance

Bevezetés

A sokoldalú, jó akusztikai tulajdonságokkal rendelkező akác eddig méltatlanul mellőzött faanyag volt a hangszerfák között. Térhódítása az ütős dallamhangszer gyártásban várható, hol eddig kizárólag a Honduraszi rózsa (*Dalbergia stevensonii*) és a Padouk (*Pterocarpus darbergioides*) voltak jelen. A NyME Roncsolásmentes Faanyagvizsgálati Laboratóriumában végzett vizsgálatok kimutatták, hogy az akácot akusztikai tulajdonságai alkalmassá teszik hangszerek, azaz marimba és xilofon készítésére (Wittmann és tsai. 1999).

A Nyugat-Magyarországi Egyetemen már több eredményes kutatás foglalkozott hangszerekkel, azon belül is a marimbával és annak kisebb változatával, a xilofonnal. A mélyreható munka eredményeként, mint minden új, feltáratlan területen végzett kutatás esetében, itt is merültek föl akkor még homályos pontok,

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❖ Taschner Róbert okl. faipari mérnökhallgató, NyME Faipari Mérnöki Kar