Doctoral (PhD) thesis

ACOUSTIC MAP OF BLACK LOCUST TREE

Miklós Horváth

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Abstract

Previous studies have demonstrated that Black locust has excellent acoustic properties, similar to Dalbergia. Recently Black locust has been used as raw material for xylophone and marimba bars. Instrument makers are interested in getting top quality material. The distribution of different acoustic properties is determined in a whole tree from the ground level to the top. Sound velocity along the grain, modulus of elasticity and logarithmic decrement has been measured on small size specimen. Two dimensional representation of the mentioned properties is prepared. Based on the investigation the acoustically most valuable part of the tree is localised.

Introduction

The first xylophone at the University of West Hungary was made by the participants of a special course for instrument makers in 1996. They found that among the species available at the University it was the Black locust material which was one of the best material for xylophone, because its sound last long. After this founding systematic study was carried out to evaluate Black locust as the material for xylophone and marimba. Students built several instruments, selected the material based on acoustic properties, learned that the quality of the material depends on its origin, fast growing material was not suitable for making instruments, and some slow growing sample showed medium or low, others high acoustic quality. The aim of this work is to find the location in a tree where the best quality material is growing.

Black locust is a rather common species in Hungary, the third most important tree species in the Hungarian forest, available all over the country. Its traditional utilisation is fire wood because of its high density, and the first glue-laminated beam was made from Black locust more than 40 years ago because of its high strength.

Material and methods

For the PhD study a Black locust forest section was selected in the south-western part of the county, where the growing speed is low. The tree selection was made using stress wave velocity measurements. Stress wave velocity was measured at breath height in the forest at the north side of 40 trees. The span between the sensors was 1 m. The measured velocity was in the range of 3700 and 4600 m/s. A single tree with high velocity (4500 m/s) and with an optimal shape and diameter (42 cm) for the investigation was selected. After feeling, pruning, a 1.5m long log section was transported to the University for further study.

As a first step, the end of the 1.5 m long log section was cut for tangentional velocity determinations, and then 2 cm thick planks were sawn at the workshop of the University using a band saw. In green condition 20 by 20 by 500 mm size specimens were prepared soon after feeling the tree. Close to the top the tree were the diameter reduced smaller samples, 15 by 15 mm were prepared. The specimens were carefully numbered, so the original position of the specimen in the tree is known.

In the frame of the investigation those parameters were selected which are sensitive for the acoustic characterisation of the material. The density, velocity, logarithmic decrement and longitudinal shrinkage were measured. The aim of the longitudinal shrinkage determination was to clarify whether tension wood existed in the test tree or not. For this reason we measured the length of the specimens in green condition and dry condition. There was no reaction wood in the test tree. The samples were naturally dried and the moisture content was 9-12 %.

For the velocity determination we used the longitudinal vibration technique. The end of the specimen was hit by a small wooden hammer, and at the opposite end a microphone registered the sound. A PC based FFT (Fast Fourier Transformation) analyser measured the sound frequency.

The definition of the logarithmic decrement (LD) is: $LD=\beta T$ where "β" is the parameter of the exponential function covering the vibration curve. „T" is the period of time, inverse of the frequency. The LD is dimension less quantity. The physical interpretation of LD is a characterization of the damping capacity of the material. If

LD data is high, the damping is fast, signal last short. If the LD data is low, damping is slow, signal last long. LD data is basically independent on frequency. LD is influenced by the following parameters: internal friction in the material, sound radiation, and absorbtion on the boundaries like support. We can minimize the effect of support absorbtion by selecting suitable supporting material (foam or rubber) and selecting optimal location for support e.g. nodal point or sample.

Logarithmic decrement was measured on dry samples. The specimen was supported at the nodal point (22 and 78% of the length). Bending vibration was generated by a hammer impact at the centre of the specimen. The microphone was placed close to the impact point. The evaluation of the sound signal was done by PC based FFT Analyser. The logarithmic decrement was measured by two FFT analyses. The second FFT was made a bit later relative to the first one. The time delay and the FFT peak amplitude ratio gives the dimensionless logarithmic decrement data.

A new design shear sensors were used for the determination of the shear wave transit time. Shear wave velocity and modulus was calculated. For verification of the test results, other methods are also applied for shear modulus determination on hardwood and softwood samples.

Results

The length of the black locust tree was 25.5m and more than 1000 specimen were prepared for density, p-wave and shear wave velocity, longitudinal shrinkage, and logarithmic decrement determination. 17 piece of 10 cm thick disk cut for tangential velocity determination perpendicular to the fibers. Dynamic hardness and the location of the juvenal – matured wood transition determined in two levels of the tree.

The p-wave velocity data in fiber direction basically determines the location of the best quality wood material. The measured sound velocity data of the air dryed samples was in the range of 4000 and 5600 m/s. The highest velocity was found in the 3rd and 5th log section, e.g. 3 – 7 m from the ground level. The velocity distribution in a given level indicates clearly the distribution of the juvenile and matured wood material. The higher velocities in the matured zone were found. The wood material close to the ground supposed to be the top quality, but the measurements showed that the velocity is a bit lover than at 3 – 7 m level. The reason can be the high mechanical stresses at the ground zone and the natural taper resulting less parallel fibers.

The measured density data are close to those published in the literature and almost uniform in the whole tree, except a high density spot close to the top of the tree. According to the calculations, using the density and velocity measurements the best acoustic properties in the tree, at the log section 3 – 5 e.g. the 3 - 7 m level was found.

The average shear modulus data is decreasing from the ground level to the top. The ratio between modulus of elasticity and shear modulus (E/G) is a good indicator of juvenal wood. The E/G values are high in the juvenile zone, close to the pith. In fact this material is not the best in acoustic point of view, but useful in handling the double tone phenomena. Certain tone bars bending frequency is close to the torsional frequency and results two sounds. Eliminating the unwanted double tones using high E/G material is possible. In the tuning procedure when the double tones come out, the instrument maker need to use high E/G raw material to shift the torsional frequency from the bending frequency.

Lower the logarithmic decrement, the material acoustic value is higher. The material has low logarithmic decrement is suitable for instruments, and available in the matured wood region. The average, and also the minimum logarithmic decrement material in the log position 3-5 e.g. 5-7m height was found. It is a fortunate condition that the same optimum position found as in case of velocity. For instrument maker the low logarithmic decrement material at higher level can be important, especially when searching for high E/G material to solve the double tones problem.

Conclusions

The full three dimensional acoustic map of a black locust tree was generated. The selected tree height is 26m, age is 32 years. The tested raw material is really good material for percussion instrument like xylophone and marimba. The results help to find, where good material for instruments is located inside the tree. It is recommended for the instrument maker to go to the forest when the tree is harvested and select the most suitable log section for purchase. In this way cost reduction and quality improvement can be achieved. Other hand the full log and lumber processing steps including drying can be controlled.

The measurement pointed out, that large deviation in elastic properties can be found inside the tree. This deviation is influencing the instrument manufacturing processes. One of the results is that the double tone phenomena can be handled by design, using suitable E/G material. The instrument maker can save time and money by proper handling the difficulties related the double town.

The boundary of juvenile – matured wood and the difference in acoustic properties of the two materials pointed out that importance of selecting matured wood for instruments. However in special case – handling the double tones - using juvenile wood, located close to the pith is the solution.

The research has been documented and published in the following publications

1.) Horváth M., Divós F., - Faanyag rugalmas állandóinak dinamikus meghatározása, összehasonlítása - Faipar - LIV. évf. 2006/4, 3-7 o.

2.) Horváth M, Divós F - Acoustic Properties of Black Locust Trees – Proceedings of the 15th International Symposium on Nondestructive Testing of Wood - 129-132 o.

3.) Horváth M, Divós F - Acoustic properties of Black locust (Robinia pseudoacacia) wood with regard to percussion instrument manufacturing – The Third Conference on European Hardwood Research and Utilisation in Europe – Conference proceedings - 72-79 o.

4.) Ott Á, Horváth M, Divós F, - Dimension stability of beech lumber predicted by variations in stress-wave velocity – The Third Conference on European Hardwood Research and Utilisation in Europe – Conference proceedings - Abstract - 59 o.

5.) Horváth M, Divós F, Dimitrios T - Comparsion between Different Dynamic Shear Modulus Determination Techniques on Robinia Pseudoacacia Specimens - 16th International Symposium on Nondestructive Testing and Evaluation of Wood

6.) Csóka L, Varga B, Horváth M - Wavelet transzformációval szétválasztott akácfa juvenilis és érett farészeinek kémiai feltárása – Papíripar LIII. évf. 1. 2009

7.) Horváth M. - A 15. Nemzetközi Roncsolásmentes Faanyagvizsgálati Konferencia - Faipar - LIV. évf. 2007/3, 35 o.

Main conclusions of this research work

The main conclusions of this doctoral work can be summarized as follows:

1. The distribution of acoustic properties within a black locust tree trunk has been mapped in order to find the optimal zone for manufacturing of wooden percussions. Requirement is expected in this area of high speed of sound, high-density, low logarithmic decrement value. After examining more than 1000 specimen, it can be stated that the most appropriate instrument making materials can be found in a 25.5 m tall acacia at 3-7 m in height, in the matured wood zone.
2. Acacia specimens showed that the shear modulus measurement - so far as possible for new and fast method of measurement - the shear wave propagation time of clip-on sensors suitable for measurement. Please note that the speed of propagation can be directly calculated.
3. Distribution of the E/G ratio has been mapped within a log in order to find a solution for so far an unsolved problem in instrument making. It is possible to eliminate the double sounds from the higher voice range of xylophone bars, which helps to decrease the refuse materials. Beside the commonly used bar thickness (~22 mm), the longer bars (220-200 mm) has significantly lower (8-9) E/G ratio, while the shorter (200-130 mm) ones have high (<16) E/G ratio which leads as a possible way to avoid the problem. Significantly higher (<30) E/G ratio of wood can typically be found around the pith.
4. The selection criterion for raw material of a wooden percussion is the long last sound. In order to meet this requirement low (>20) logarithmic decrement raw material is necessary. Low (>20) logarithmic decrement property can be found in a 25.5 m tall, black locust tree at 3-7 m height, located in mature wood.