INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 1/2025 (27): 7–12

HOW TO FIND RESONANCE WOOD?

Nikolay Bardarov[1], Nikolai Minkovski[2]

[1]*University of Forestry, Department of „Mechanical Technology of Wood", Sofia, Bulgaria, E-mail: niki_bardarov@abv.bg*
[2]*University of Forestry, Department of „Mathematics, Physics and Informatics", Sofia, Bulgaria, E-mail: nminkovski@ltu.bg*

ABSTRACT

Wood is widely used to produce sound emitters (decks) of musical instruments. This wood is called resonant. Although this name does not accurately reflect the physical nature of the phenomena occurring in wood when used in musical instruments, it is widely used in practice and in technical literature.

The article examines the parameters that make a wood resonant. It is suggested that wood should be tested only when it meets part of the requirements and does not have good sound qualities. In this way, the influence of one or several factors can be isolated, and their importance on the quality of the wood can be determined.

Key words: resonance wood, spruce, musical instruments

INTRODUCTION

For a wood to be resonant, it must meet several anatomical, physical, etc. requirements. The width of the annual layers should be, depending on the type of musical instrument, no more than 1-3-6 mm (for violins narrower, for cello and double bass – wider). The content of latewood in them should not be more than 30% (for concert grand piano soundboards, no more than 20%). In addition, the resonant wood must be even-layered and not contain any defects (Fedyukov 1988, Bukur 1995).

In bowed (strung), plucked and keyboard instruments, the energy of string vibrations is transmitted to a soundboard designed to amplify the sound and form its timbre (the characteristic sound of the instrument). A significant portion of the energy transmitted from the string to the soundboard is wasted within the soundboard material, as well as where it is attached to the body of the instrument. Only 3-5% of the total energy is emitted into the air in the form of sound (Holz 1973, Bukur 1995).

The quality of the material used for producing parts (decks) for musical instruments should have a high value of the ratio of the modulus of elasticity of longitudinal deformation and low density. This provides the highest sound emission, as estimated by the proposed acoustic constant of Andreev (Kolesnikova 1996, Fedyukov 1988):

$$K = \frac{C}{\rho} = \sqrt{\frac{E}{\rho^3}},\ m^4.kg^{-1}.s^{-1} \qquad (1)$$

where:

E is the dynamic modulus of elasticity of longitudinal deformation (Young's modulus), $N.m^{-2}$;

C – speed of sound, $m.s^{-1}$;

ρ – wood density, $kg.m^{-3}$.

The highest value of the acoustic constant is characteristic of spruce, fir and cedar wood, which is approximately 12 $m^4.kg^{-1}.s^{-1}$.

Recently, a method has been used to determine the acoustic constant from cylindrical samples of 4.5 mm diameter drilled radially from the trunk of a growing tree with a Pressler drill. The speed of sound propagation in wood C (across the fibres) can be measured by the ultrasonic method, the K index being about 3 times smaller than the standard one (Kolesnikova 1996).

RESONANT WOOD

To describe this term, in fact, several requirements for wood must be met: physical, morphological, anatomical, chemical, etc.

From the physical requirements, not only the high speed of sound but also the high degree of anisotropy of the wood can be specified. This means that while longitudinally, the fibre should be more than 5100 $m.s^{-1}$, this value should not exceed 1200 m.s-1 transversely. In addition, the value of the acoustic constant is used to characterize the resonance wood in combination with the damping index. Thus, good wood must have not only a high value of K, but also a high attenuation, determined by the value of the attenuation decrement δ, to successfully filter sound.

In wood science, the properties of wood are considered and, if possible, explained at different levels of scale (Fig. 1):

- geometric – the tree, stem or large board;
- morphological (macroscopic) – a small board and what is visible on it with the naked eye or a magnifying glass;
- anatomical (microscopic) – it is represented by the tissues that make up the wood or a group of cells with similar characteristics (at an optical magnification of about ×30 to ×400);
- submicroscopic – it examines the structure of the individual cell and its cell wall (at an optical magnification of about ×500 to ×1000);
- molecular – it examines the wood substance as such, the structure of the cellulose matrix, the reaction of chemical compounds under various loads and processes.

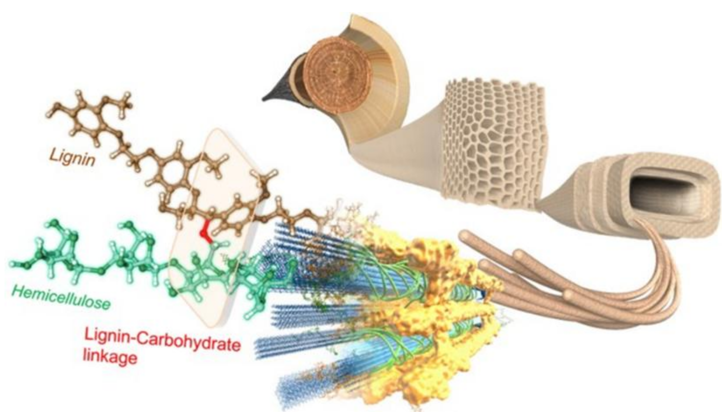

Figure 1: Scale levels when viewing wood.

From the silvicultural factors (at the geometrical level), the special conditions of the habitat can be indicated, which guarantee the formation of stems with homogeneous wood and with small stresses during growth. However, it has been proven that even in a stand with many resonant trees, not all of them have good acoustic characteristics. It is very likely that this is due to the distribution of growth stresses.

Spruce, which is most commonly used for decking, has a horizontal root system. Roots are shallow, and their placement has a direct impact on growth stresses. Similar research was done in Russia by Kolesnikov (2008). Investigating resonance plantations and the conditions under which they develop, the author even found that resonance trees can be established by a specific shape of the scales of the spruce cones.

However, in their research, the authors consider the root system only of resonant ones. It is the difference in the root systems of resonant and non-resonant trees that may determine the reasons why trees distribute growth stresses throughout their stems.

Of the morphological requirements (macroscopic scale), the most important is attached to the uniformity and width of the annual rings. Wider annual rings make the wood resonate well at a lower vibrational frequency. This is why such wood is used to make double bass decks. Wood with narrower annual rings is used for cellos, and wood with the narrowest is used for violin production (Fedyukov 1988, Bucur 1995).

Of the anatomical requirements (microscopic scale), the structure of the annual ring is of the greatest importance. The percentage of latewood is precisely determined (between 20 and 33%). The size and location of the transition zone are also regulated. Some authors attribute influence to the quantity, size and location of the core rays, others to the courtyard pores (Holz 1981, Ulvich 1961, Ylle 1976).

Such claims are based on research that has found open pore pores in the wood of the decks of the world's most famous and fine violins. It is very likely that the old masters infected the wooden blanks with bacteria that degraded the pores and torus of the cells (Reinprecht 2016). However, there is wood that fulfils part of the anatomical requirements and yet is not used for resonance.

These are the trees growing in Siberia, which have narrow and even annual rings, but they are not known to be used in the manufacture of musical instruments. Similar statements can be made about the trees growing in Scandinavia. There is a so-called "low-resin spruce "which, however, is not used to make decks.

It is well known that the resonant wood must be slightly resinous, i.e., have few resin canals. In Bulgaria, some luthiers even use fir wood (if they have a little latewood). This wood is known to have no resin canals at all. According to them, instruments made from fir have a "more velvety "sound.

For sub-microscopic construction, resonant wood currently has fewer requirements. The influence of cell wall structure on the resonance properties mentioned above has not yet been fully established. It is not clear how the differences between the thickness, structure and chemical composition of the radial and tangential walls affect these properties. These walls are known to be different because of the different degrees of cambium division (much more often periclinal than anticlinal).

At this level, for example, the anisotropy of drying and swelling can be explained (Todorova 2024). The same applies to the amount of crystalline areas in the cellulose microfibrils of the radial and tangential walls. There is a direct relationship between the moduli of linear deformation and the number of crystalline sections (fig. 2). They show different behaviour to wood studied for piezoelectric properties (Kollmann and Côté 1968).

It should be noted that the soundboards (i.e. the decks) also have this orientation with respect to the directions in the stem. If these test bodies in the figure are enlarged in a radial direction, the shape of a resonator board is obtained. It is possible that there is a connection between the minimum values and the placement of the "soul "in strach musical instruments.

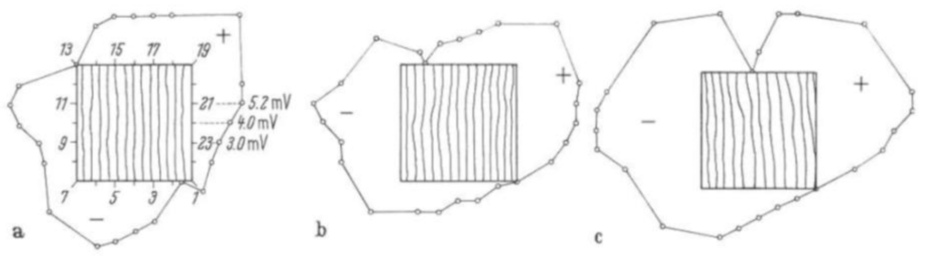

Figure 2: Three piezoelectric stress profiles in different cross-sections of a specimen. a) In cross-section distant 18 mm from the end of the impact; b) at 58 mm from the impact end; c) At 64 mm from the shock end (Kollmann and Côté 1968).

There is interesting research on the chemical composition of proven resonance wood (molecular level). It has been found that there is a greater amount of calcium in it. There is still no consensus as to whether this amount was achieved after soaking the wood in the corresponding solution or whether the calcium was acquired during the growth of the tree. It is clear that in the first variant, calcium will be more in the early wood (due to the more significant cell gaps), while in the second, it will be in the latewood (due to the thicker cell walls).

Our silvicultural literature shows that a higher amount of calcium leads to an increase in soil temperature and, hence, an increase in the upper limit of the range of spruce plantations. There, however, the insolation is weaker. From there, the annual rings are narrower and more uniform. Also, in the higher parts of the range, wood with more lignin is formed due to more UV radiation. We do not know whether the resonance trees harvested in the Alps are more from northern or southern exposures.

In addition, there is a large difference in the soil characteristics of these two exposures. From the south, it is poorer and drier, which may suggest narrower annual rings despite a good amount of sunshine. Conversely, on the northern exposures, the soils are richer and moister, which would explain the more uniform widths of the annual rings. These trees grow in cooler temperatures and a shorter growing season, which results in narrower annual rings.

The long storage of the logs should be mentioned first for the activities related to the cultivation and processing of resonance wood. Harvested wood was stored for up to 50 years. This is probably related to the gradual equilibration of growth stresses in the stems, although it is not known what form the blanks were in. Now, in our country, the following distribution of storage of wood for parts for musical instruments is observed:

- for mass (cheapest) instruments – from 3 to 5 years;
- for the orchestra (the most common) – from 10 to 15 years;
- for the master (most expensive) – more than 30 years.

This shows an interesting fact: the Italian masters were not single geniuses who produced the best violins but were inheritors of deep traditions in this art (luthiery). At least they were not born when their ancestors mined the blanks for their tools.

Although many authors attach importance to varnishes, etc., factors in good-sounding instruments, the wood is undoubtedly of prime importance. It is known that during exposure for several decades (i.e., ageing), the content of lignin and hemicelluloses changes. Such wood is more resistant to the influence of temperature and atmospheric humidity, and the instruments made from it have greater stability of sound characteristics.

CONCLUSIONS

To find the best wood, we probably need to find a material that meets all the requirements (physical, anatomical, chemical, etc.). However, this is very difficult, if not impossible. In our opinion, looking for wood that meets some of the requirements is more proper but does not have resonant qualities. Then, we will probably be able to isolate one factor from the rest and determine its weight relative to the quality of that wood.

A good resonant wood redistributes its internal stresses in such a way that, when set to vibrate, it makes a special and precise ratio of vibration in the case material and the air in the violin's resonator box. Every one of the factors (from the silvicultural conditions of the environment to the chemical composition) has a relation to this mode of oscillation. Because of that, this wood manages to filter the sound so that we hear the best part of it.

REFERENCES

BEKTHA, P. 2002. *Untersuchungen einiger Einflussfaktoren auf die Schallausbreitung in Holzwerkstoffen*. Holz als Roh – und Werkstoff. 60, No 1, 41–45.

BENSON, D. 2000. *Mathematic and music*. 112–121.

BUCUR, V. 1995. *Acoustics of wood*. CRC Press Inc.

BUCUR, V., A. CLEMENT, M. BITSCH, C. HOUSSEMENT. 1999. *Acoustic properties of resonance wood and distribution of inorganic components of the cell wall*. Holz Roh-und Werkstoff. 57, No 5, 103–104.

CULIK, M., *et al*. 2000. *Experimentalne studium vybranych problemov materialoveho inzinierstva akustickych gita*r. Zvolen, 14–28.

DELUNE, L. 1982. *Le bois dans les industries de la musique*. Revue forestiere fransaise. 29, No 2, 143–150.

FEDYUKOV, V.I. 1988. *El resonancenaya*. Yoshkar–Ola, 37–56; 110–124; 185–194.

FEDYUKOV, V.I. 2005. *Research on the biophysical basis of the formation of unique acoustic properties of resonant wood*. 03200100788 UDC 681.817.061.6, GR 01200007135.

FEDYUKOV, V.I. *and others*. 1998. *Form of seed scales as a diagnostic sign of resonance properties of wood*. Izvestie uzov Lesnogo zhurnala. No 1, 23–30.

GOST 9463–60 1974. *Influence of the quality of the logs on the yield and sorting by quality of the resonant wood materials*. – Mechanical wood technology, Minsk, No 4, 79–83.

HOLZ, D. 1973. *Akustische eigenschaften von resonanzhols*. Holztechnologie. 14, No 2, 113–114.

HOLZ, D. 1975. *Kriterien zur Bewertung von Resonanzholz im Musikinstrumentenbau*. Holztechnologie 4 No 2, 35–43.

HOLZ, D. 1981. *Zum alterungverhalten des werkstoffes holz – einige ansichten, untersuchungen, ergebnisse*. Holztechnologie. 22, No 2, 80–85.

HOLZ, D. 1984. *Uber einige Zusammenhange zwischen forstlich–biologishen und akustichen Eigenschaften von Klangholz (Resonanzholz)*. Holztechnologie 25 (1) 31, 31–36.

HUANG, C.-L., H. LINDSTROM, R. NAKADA, J. RALSON. 2003. *Cell wall structure and wood properties determined by acoustics – a selective review*. Holz als Roh-und Werkstoff. 61, 321–335.

ILIC, J. 2003. *Dynamic MOE of 55 species using small wood beams*. Holz als Roh-und Werkstoff, No 61, 167–172.

KOLESNIKOVA, A.A. 1996. *Mathematical basis for operational selection of oils with high resonance properties*. The woodworking industry, No 5, 20–21.

KOLESNIKOVA, A.A., P.M. MAZURKIN. 1997. *Change in the properties of spruce wood along the stem radius*. The woodworking industry, 8.69.23. No 5, 23–25.

MAKARYEVA, T.A. 1968. *Influence of various factors on the value of the acoustic constant of resonant wood*. The woodworking industry, No 10, 45–52.

MULLER, M. 2001. *Acoustic properties of softwoods and their biological diversity: Why is Norway spruce superior for musical instruments*. ESRF Grenoble. SC–704.

PISHCHIK, I.I. 1998. *Selection criteria for spruce wood for musical instruments.* The woodworking industry, No 1, 10.69.32, 24–26.

PYLE, R.W. jr. 2003. *Sound quality of brass–wind musical instruments*. 146th Meeting Acoustical Society of America.

SAPOZHNIKOV, A.S. 1981. *Results of a study of the acoustic properties of resonant wood*. Scientific works of the Moscow Forestry Institute, No 131, 15–17.

SASAKI, T., *et al*. 1988. *Effect of moisture on the acoustical properties of wood*. Journal Japan wood research society, 34, No 10, 794–803.

TAYLOR, C.A. 1965. *The phyzics of music sound*. The English Universities press LTD London EC4 НБ II38462, 533–539.

TODOROV, M.P. 1970. *Comparative studies on the structure and physico–mechanical properties of spruce (Picea abies Karst.) wood as a function of altitude*. Collection of scientific works, vol. 18, 61–68.

TONOSAKI, M., T. OKANO, I. ASANO. 1983. *Vibrational properties of sitka spruce*. Journal Japan wood research society, 29, No 9, 547–552.

ULVICH, W. 1961. *Holz königliches werkstoff des musikinstrumente baumes. Riotte Berliner Holzwirtschaf*t. Beilage zum Holz–zentralblatt, 154–156.

VINTONIEV, I.S., S.S. MERGEL, E.A. STYBRIK. 1981. *Effect of extraction on the acoustic properties of resonant wood*. Izvestie Vuzov Easy journal. No 5, 85–86.

WAGENFUHR, R. 1989. *Anatomie des Holzes VEB Fachbuchverlag Leipzig*.

WOOD, A. 1977. *The physics of music*. Издательство НБ ИЛБ12W83.

YANO H. 1993. *Controlling the timbre of wooden musical instruments by chemical modification*. Wood Science and Technology, No 27, 287–293.

YANO, H., T. YAMADA. 1985. *Study on the timbre of wood*. Journal Japan wood research society. 31, No 5–9, 719–724.

YLLE, R. 1976. *Eigenschaften und verarbeitung von fichtenrezonanzholz fur meistergeigen*. Holztechnologie. 17, No 1, 32–35.

YLLE, R. 1978. *Osetreni a vlastnosti rezonancniho dreva smrku pro mistrovske housle*. Drevo. 33, No 5, 133–138.

UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2025

INNO vol. XIV Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal

Vol. 14/ p. 1–104

Sofia 1/2025

ISSN 1314-6149

e-ISSN 2367-6663

Edition of

FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

Cover Design: Desislava Angelova

Printed by: INTEL ENTRANCE
Publisher address: UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
http://inno.ltu.bg
http://www.scjournal-inno.com/

THIS ISSUE CONTAINS PAPERS PRESENTED AT

TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE

INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN INNO 2024

7 – 9 October, Hotel Imperial Plovdiv, a member of Radisson Individuals, Plovdiv, Bulgaria

ORGANIZED BY FACULTY OF FOREST INDUSTRY, UNIVERSITY OF FORESTRY, SOFIA, BULGARIA

WITH THE KIND SUPPORT OF

Twelfth International Scientific and Technical Conference INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN INNO 2024, is supported by the National Science Fund, Bulgaria with co-financing agreement № КП-06-МНФ/40 от 13.08.2024

CONTENTS