Violin Top Wood Qualification: Influence of Growth Ring Distance on Acoustical Properties of Red Spruce

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ABSTRACT

No evidence was found of a relationship between physical and acoustical properties (density, modulus of elasticity, index of merit) and external aspects of Italian red spruce (mainly growth ring distance). Growth ring distance was determined optically for 21 planks of red spruce, cut both longitudinal and radially. Moduli of elasticity E_L and E_R were obtained by the measure of the deflection, under known weight, of beam-shaped samples of spruce.

INTRODUCTION

Most luthiers base their choice of wood for soundboards on external aspects of wood, such as growth ring distance, straightness of grain (both radial and tangential) and the absence of defects like resin pockets and knots. Large growth ring distance is often loosely associated with low density, and narrow growth ring distance with higher elastic moduli, although craftsmen disagree on these points. Is the appearance of spruce wood any indication of physical and acoustical properties?

CHOICE OF SPRUCE FOR TOP PLATES

Commonly, red spruce (Picea abies) is used for top plate, bassbar and soundpost in bow instruments and also for guitar and piano soundboards. The quality of a board of red spruce is evaluated threefold before it becomes part of an instrument:

1) Forest Corps make an initial selection of whole trees, cut them in logs and quarters, and specify the destination for the wood (i.e.: musical instruments, furniture or building industry);

2) Specialized dealers of wood for musical instruments (less frequently luthiers) qualify wood using a certain number of classes (i.e.: good - medium - poor quality);

3) Luthiers make their own final selection according to their beliefs on the relationship between wood appearance and wood properties.

Wood with defects is rejected in the first two steps. Subsequently luthiers analyze the external appearance of boards, in particular the growth ring distance along the main section of wood (radial and transverse) and use this qualitative information to judge if a piece of spruce is acceptable for violin, viola or cello top plates. Physical and mechanical properties of wood are rarely measured in any of these steps, although they affect the frequency response of soundboard. Even density, one of the easiest properties to be measured, is rarely taken in account, and moisture content is often disregarded.

In this paper we compare growth ring distance along a specimen's width with wood density and moduli of elasticity (E_L and E_R) in the radial and longitudinal direction of specimens of red spruce. Many studies indicate that these parameters are the most critical in the top plate's frequency response. This work is based on a graduation thesis in Materials Engineering at Padova University, Italy.

> **"Is the appearance of spruce wood any indication of physical and acoustical properties?"**

IMAGE ANALYSIS APPLIED TO WOOD CHARACTERIZATION

Growth ring distance

Image Analysis, is used here to evaluate growth ring distance for the specimen's transverse section. First, an image of each radial specimen is captured using a scanner, then the image is analyzed using image analysis software. Late parts of the rings (the darkest) are defined, and their position in the x-direction is measured and tabulated. The "amplitude" A of each growth ring is defined as the distance between the ends of two adjacent rings (Fig. 1). A similar

Figure 1. Growth ring distance (*d*) and amplitude (*A*).
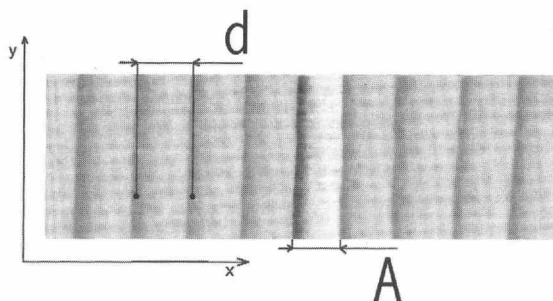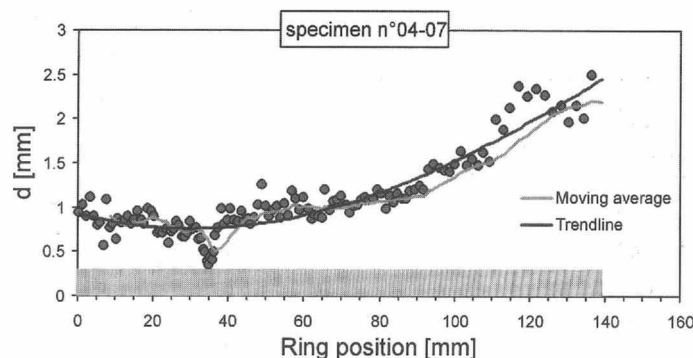

Figure 2. Image analysis of a red spruce specimen.

quantity, "growth ring distance" *d* is the distance between the centers of the late part of two adjacent rings. The "growth ring distance" *d* is the quantity actually measured, and can be assumed equal to *A* for the purposes of this work.

Data (position of the center and area of each late ring) are exported to a spreadsheet, and an average value of *d* is calculated. Then data can be plotted in a graph (Fig. 2), where each point represents a summer growth ring, with its position in the specimen transverse section on x-axis, and its distance with adjacent ring on y-axis. An image of specimen section can be superimposed to this graph, to show the agreement between physical features and image analysis.

Usually *d* decreases from pith to bark, but in some specimens (Fig. 2) the distances are irregular. In order to estimate this irregularity, an "index of irregularity" (*I*) is calculated as follows (sigma indicates standard deviation):

(Equation 1)
$$I_r = \frac{\sigma(d_i)}{d}$$

Growth ring distance is influenced by the cut of planks: while a radial cut leads to an orthogonal relationship between rings and the plate radial surfaces, a non-radial cut produces variations on the angles, and can generate apparent distances larger than the corresponding actual distances. Non-radial cuts in a number of planks for pianos and violin blanks have been observed. Commonly, luthiers use red spruce that has been cut at some angle from the radial direction.

Late Growth Percentile

Another anatomical feature considered was $L_g\%$, the percentile of the late growth of the ring (Equation 2), where A_s is the area related to summer growth, and A_l is the area related to late growth.

(Equation 2)
$$L_{g\%} = \frac{A_l}{A_l + A_s} \cdot 100$$

ACOUSTIC PARAMETERS AND THEIR DETERMINATION

Wood physical and elastic parameters

According to many studies [1, 5], frequency response and acoustic efficiency of top plates are mostly influenced by the following parameters:

1) Density
2) Moduli of elasticity E_L and E_R.

Besides being anisotropic, red spruce also exhibits inhomogeneities in its structure. For example, there are different dimensions of rings in transverse section. This causes a variation in material properties; density and Young's modulus E_L vary, if measured on different points in radial direction, as reported in this study.

Preparation of Spruce Specimens

Twenty-one planks of Italian red spruce, originally cut for piano soundboards, were taken from Fazioli and Ciresa stock. All of the wood came from the eastern Alps. Most of the wood came from the Paneveggio forest, located in the Fiemme valley, near Trento, Italy (plank number 8 is from Valcanale forest, in the il Friuli region, near Udine).

All the planks were seasoned for more than 2 years before being cut into 300 specimens. Each plank was cut into seven pieces with the major axis in the longitudinal direction, and seven pieces in the radial direction. Specimens were then allowed to stabilize for more than 30 days in a room with a controlled atmosphere (23°C and 50% relative humidity). All the measures of density and moduli of elasticity have been carried out in these conditions. Average values for density, longitudinal and radial moduli were calculated for each plank.

Moduli of Elasticity (E_L, E_R)

The determination of moduli of elasticity can be achieved by both static and dynamic methods. Static methods measure the

Figure 3. Comparison between growth ring distance (*d*), index of merit (*M*) and density, for 21 samples of Italian red spruce.
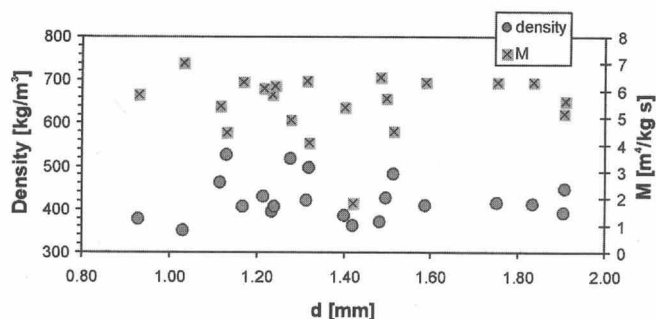

Figure 4. Comparison between index of irregularity (*I*ᵣ), index of merit (*M*) and density, for 21 samples of Italian red spruce.
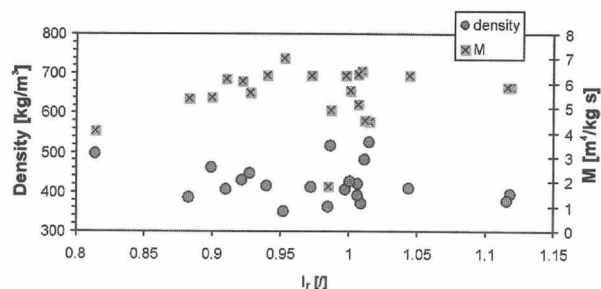

Figure 5. Comparison between growth ring distance (*d*) and density, for 21 samples of Italian red spruce (line shows data from Giordano [4, p. 840]). Vertical brackets indicate standard deviation.
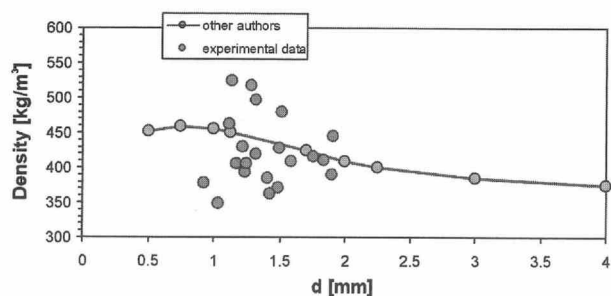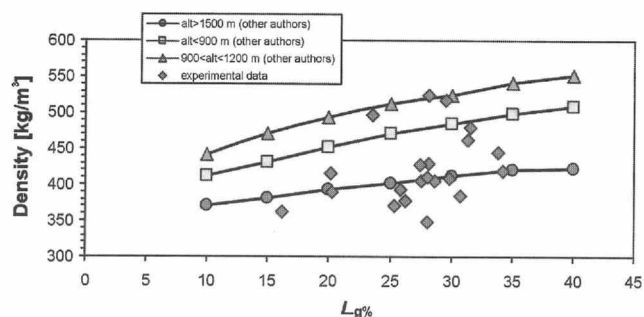

Figure 6. Comparison between L_g% (late growth percentile) and density, for 21 samples of Italian red spruce (lines show data from Berger, as reported in Giordano [4, p. 839]).

deformation of a beam-shaped specimen under known weight (or the measure of weight necessary to produce a standard deformation). Specimens can be loaded in compression-tension, flexure or torsion condition. Dynamic methods are based on the measurement of natural frequency of a beam or plate-shaped specimen, or (as in the ultrasonic methods) the measurement of the speed of sound in precise directions. Static and dynamic methods lead to different results because of the mechanical behavior of wood, a material that can be considered viscoelastic, in a first approximation.

A static method has been adopted in this study for practical reasons: resonance methods and ultrasonic testing requires experimental set-up and knowledge that most luthiers do not have, while a simple apparatus for static testing can be easily self-made, as reported by Wood [7] (other authors reported about self-made dynamic testing [3, 5]). On the other hand, the purpose was to make a comparison between different planks of red spruce, and it was possible to underline great differences in the values of the Young's moduli, thus confirming the validity of the experimental method used.

Index of Merit M

The acoustic efficiency of top plates is influenced both by geometry and wood character. According to Barlow [1} and Meyer [6], information on the acoustical efficiency of wood can be estimated by an Index of Merit *M* (Equation 3). Woods with higher values of *M* are more suitable for soundboards.

(Equation 3)
$$M = \frac{(E_L E_R)^{1/4}}{\rho^{3/2}}$$

COMPARISON BETWEEN GROWTH RING DISTANCE AND ACOUSTIC PROPERTIES

In Figures 3-6, mechanical and acoustic properties (E_L, E_R and *M*) are compared with the characteristics of growth rings: *d* and I_r. Each point in the graphs represents an average property for a single plank.

CONCLUSION

A functional relationship cannot be established between the spacing of growth rings and acoustic properties for 21 samples of red spruce from northern Italy. This suggests that optical regularity and dimensions of growth rings are unreliable indicators of physical properties.

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What is the Weight of a Good Violin?

(The following data were recorded at the Library of Congress (Washington D.C.) and the National Music Museum (Vermillion, So. Dak. Note: most modern violins weigh about 475 g):

Maker (date, name if applicable)	Instrument	Body Length[1]	Weight (g)
	Italian makers		
Andrea Amati (1574)	7/8 violin	342.0	346
Andrea Amati (1577)	4/4 violin	353.0	353
Hieronymus Amati (1604)	free back plate	342.0	82
Hieronymus Amati (1604)	free top plate	340.5	46
Hieronymus Amati (1609)	7/8 violin	340.0	322
Nicolo Amati (1628)	4/4 violin	353.0	381
Nicolo Amati (1654, "Brookings")	4/4 violin	354.5	419.7[2]
Brescian School (1630)	4/4 violin	356.0	330
Brescian School (1640)	4/4 violin	355.0	402
Carcassi, Tomaso (1759)	4/4 violin	357.0	380
Cerin, Marco Antonio (1792)	4/4 violin	353.0	358
Ceruti, Giovanni Battista (1801)	4/4 violin	351.0	410
Gragnani, Antonio (1788)	4/4 violin	356.0	354
Guarneri del Gesu (1733, "Kreisler")	4/4 violin	353.5	434.8[2]
Landolfi, Carlo F. (ca 1760)	4/4 violin	358.0	394
Maggini, Giovanni Paulo (1623)	4/4 violin	352.0	398
Rogeri, Pietro Giovanni (1715)	3/4 violin	327.0	316
Stradivari, Antonio (1693, "Harrison")	4/4 violin	363.0	386
Stradivari, Antonio (1699, "Castlebarco")	4/4 violin	357.0	448.5[3]
Stradivari, Antonio (1700, "Ward")	4/4 violin	354.5	427.7[2]
Stradivari, Antonio (1704, "Betts")	4/4 violin	354.0	429.3[2]

[1] Length (mm) of back plate, caliper distance.
[2] mounted with chin rest (Hill, Guarneri-style, ebony)
[3] mounted with chin rest (Hill, Guarneri-style, boxwood)