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STUDY CONCERNING THE NATURAL FREQUENCY AND DAMPING FACTOR OF THE TOP AND BACK PLATE FOR DIFFERENT TYPES OF VIOLINS

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Abstract:

The present study envisaged the modal analysis of the top and back plate of violins, in order to establish the first natural frequency and the damping factor of each plate as individual violin part. The differences between the wood species involved (resonance spruce wood – used for the top plates and curly maple wood – used for the back plates), but also the influence of the wood characteristics specific to four different quality classes of violins upon were investigated by a dynamical test, using excitation of the plate by means of a hammer and signal acquisitioning by means of an accelerometer. The results revealed that the first natural frequency of resonance spruce wood lies at about 140Hz and that of curly wood at 327Hz. The damping factor has the lowest value for the spruce top plate of maestro-class violins.

Key words: *violins; resonance wood; natural frequency; damping factor.*

INTRODUCTION

The violin is a musical instrument with strings and bow. The main parts of the violin body (Fig. 1) are: the top plate with the specific f-holes, the soundpost and the bass bar (placed inside the violin body), all these being made of resonance spruce wood, and the back plate, the bridge and the ribs, all these being usually made of curly maple, but different other species (*e.g.* poplar, willow, walnut, ash, hornbeam, plumtree, yew wood) can also be used for this purpose, in order to satisfy various aesthetical demands of the customers.

Fig. 1. Main parts of the violin body:
TP-top plate; BP-back plate; B-bridge; R-ribs.

The strings themselves have almost no air and consequently produce almost no sound. The sound is produced by rubbing the bow over the strings under different angles. The angle between the bow and the excited string decomposes in a horizontal plane the force produced by the bow into a longitudinal component (parallel to the string) and a transversal component to the string direction. The string begins to vibrate both

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transversally (in the direction of the force applied by the bow) and longitudinally - along the strings, the transverse vibrations being transmitted through the bridge to the entire volume of air in the violin body. Thus, the violin body behaves like a Helmholtz- type resonator, forming compression and dilatation waves between the top plate, the back plate and the ribs of the violin body, giving rise to intense sound. When resonance occurs, the sound intensity increases due to the intensification of the radiation inside the violin body.

The top plate has two features that significantly affect the sound output: one is given by the f-holes, which connect the air inside the instrument with the air outside, and this oscillating air is responsible for the violin's lowest resonance (the so-called natural resonance). The second feature of the violin's top plate is the bass bar, which serves several purposes: it strengthens the top plate to withstand the string pressure; it couples the vibrations of the area between the f-holes, which oscillates relatively freely, to the more constrained part of top plate closer to the neck; and it prevents energy from being wasted in higher-frequency vibrations of the body that don't produce much sound. The sound post and bass bar together break the symmetry of the violin body, thereby allowing the body to oscillate in different ways than if it were symmetrical, and generally increasing the sound output of the instrument (https://www.physicscentral.com/).

Of course, there is also a third feature, which significantly influences the sound output and this is the quality of the wood used for the top and back plate. According to the structural and physical characteristics (*e.g.* grain straightness, texture finesse, annual rings widths and their uniformity, the proportion of latewood within each annual ring, wood density etc.) of the wood the top and back plate are made of, violins are divided, according to SR 1294:1993, into four classes: maestro, professional, student and school.

The natural frequency (also called *eigenfrequency*) of a vibrating body is the frequency at which the system tends to oscillate in the absence of a driving or damping force (www.wikipedia.org citing General Physics 2012). Its value is determined by the geometrical characteristics of the source from which the wave propagates. The motion pattern of a system oscillating at its natural frequency is called the normal mode. The number of harmonics is determined by the resonator which amplifies the initial sound, adding series of its own frequencies. Thus, the quality of the wood used for the construction of a violin plays a decisive role in ensuring the acoustic quality of a musical instrument.

Previous researches regarding the values of the first vibration mode were performed by Molin *et al* (1987), who obtained for spruce plates with a constant thickness of 2.5mm frequencies between 150.5Hz and 157.1Hz, and for maple plates with a constant thickness of 3.5mm, frequencies between 351.9Hz and 362.9Hz.

Lomte (2013) reported for the top plate an eigenfrequency of 157.8Hz obtained by finite element modeling. Gough (2015) also determined the eigenfrequencies of the violin plates by finite element modeling, obtaining the value of 158Hz (second eigenfrequency) for the spruce plate and 348Hz for the maple plate (5 # vibration mode). Dünnwald (1991) proposes four frequency bands for evaluating the acoustic quality of violins. Thus, between 190-650 Hz, one can identify the fundamental acoustic characteristic of the instrument, called "signature mode"; the second frequency band is between 650-1300Hz which contains a strong response of the violin, associated with "a nasal quality in the sound"; the third frequency band between 1300-4200Hz contains the sounds which are responsible for brightness, characterized by efficient acoustic radiation and sound uniformity. The fourth frequency band, in the range 4200–6400Hz, should be relatively low in order to obtain a clear sound.

OBJECTIVE

The main objective of the present study, which is part of a broader research, was to establish the natural frequency of the top and back plate, as individual violin parts, made of resonance spruce wood, and curly maple wood respectively, but also having different characteristics, depending on the quality class of the violin for which they are selected (maestro, professional, student or school violin).

MATERIAL, METHOD, EQUIPMENT

The material used within this study consisted of eight top plates without *"f"* holes (Fig. 2, a) and eight back plates (Fig. 2, b), two for each violin class, furtherly noted with: A – *maestro* violins; B – *professional* violins; C – *student* violins; D – *school* violins.

All violin parts were manufactured and tested at GLIGA INSTRUMENTS Reghin (Romania).

Table 1 presents the wood species / assortments used for each violin class, as well as the characteristics of the wooden material involved. In Romania, the total ring width (TRW), the latewood proportion (LWP), and the difference between consecutive growth rings (Δi) are the structural criteria used to select the raw material for the manufacture of musical instruments and for their qualitative classification (Dinulică 2015).

Because the selection of the maple wood for violins uses vague terms like „curly wood", „very curly wood", „slight curly wood" etc. in order to characerise the wood grain, a quantification method for this aspect was developed. Thus, the annual ring width and the wavelength of the curly grain (λ) were measured on the radial face of the wood samples, by using a WinDENDRO Density image-analysis system (Régent Instruments 2007). The samples were scanned at a resolution of 2200 dpi. The annual ring width was measured digitally in radial direction, and the wavelength was measured in tangential direction (Fig. 3). The measurements were carried out with an accuracy of 0.001mm. The database, originally in .txt format was imported and primarily processed in Microsoft Excel.

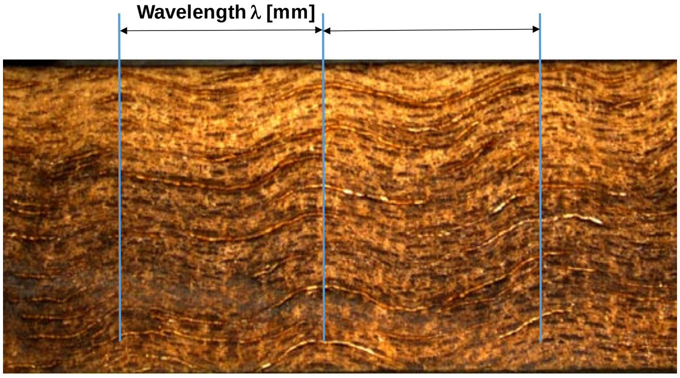
a. ***b.***

Fig. 2.
Violin plates – top plate (a) and back plate (b).

Table 1
Characteristics of the wooden material used for the tested violin plates (faces and backs)

Violin class	Wood species used for violin face and back	Wood characteristics (Dinulică 2015; Albu 2010)
Maestro	Face: resonance spruce (*Picea abies*)	**A-spruce** is the best quality resonance spruce wood TRWi ≤ 2.5 mm; LWPi ≤ 35%; average (LWPi) ≤ 20%. No more than 7 growth rings with 35 < Δi ≤ 0.8 mm are accepted.
	Back: maple (*Acer pseudoplatanus*)	**A-maple** is very curly TRWi ≤ 1.3 mm; λ≤ 3 mm
Professional	Face: resonance spruce (*Picea abies*)	**B-spruce** TRWi ≤ 2.5 mm; LWPi ≤ 37%; average (LWPi) ≤ 35%. No more than 7 growth rings with 37 < Δi ≤ 1.0 mm are accepted.
	Back: maple (*Acer pseudoplatanus*)	**B-maple** TRWi ≤ 1.5 mm; 3≤ λ≤ 8 mm
Student	Face: resonance spruce (*Picea abies*)	**C-spruce** TRWi ≤ 3 mm; LWPi ≤ 39%; average (LWPi) ≤ 37%. No more than 7 growth rings with 37 < Δi ≤ 1.5 mm are accepted
	Back: maple (*Acer pseudoplatanus*)	**C-maple** TRWi ≤ 1.7 mm; 8≤λ≤ 12 mm
School	Face: resonance spruce (*Picea abies*)	**D-spruce** TRWi ≤ 3 mm; LWPi ≤ 43%; average (LWPi) ≤ 39%. No more than 7 growth rings with cu 43 < Δi ≤ 1.5 mm are accepted.
	Back: maple (*Acer pseudoplatanus*)	**D-maple** TRWi ≤ 2.5 mm; λ →∞

a.



b.

Fig. 3.
Maple samples with different structural features used for characterising the grain curliness: a - curly maple samples; b - measuring the wavelength of the curly fibres (longitudinal-tangential view).

In order to measure the natural frequency of each violin plate (top/back plate), each plate was supported with spring elements on a table, to simulate the free structure. Then the plate was excited by an impact hammer type B&K 8204 and its response was captured by an accelerometer type B&K 4517-002. The received responses were transmitted via the conditioning device to a Dynamic Signal Acquisition System (DAQ), connected to a laptop. The capture and visualization of the signal was achieved through the software developed in LabView, and the graphic data processing was performed with the MatLab program, in order to obtain the first natural frequency (f_0) and the damping factor (n) for each tested plate. The experimental set-up is presented in Fig. 4.

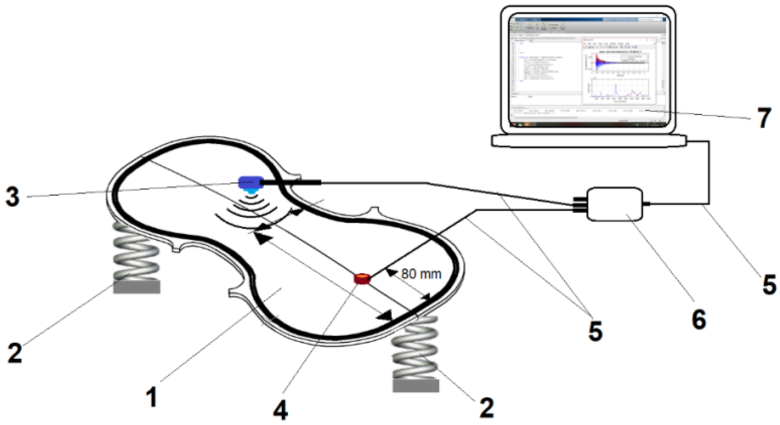


Fig. 4.
Experimental set-up: 1 - violin plate; 2 – spring element; 3 – impact hammer; 4 – accelerometer; 5 – cables; 6 – DAQ; 7 – laptop.

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RESULTS AND DISCUSSION

It is known that the natural frequencies are certain discrete frequencies at which a system is prone to vibrate. They appear as standing waves in a musical instrument (https://www.comsol.com/multiphysics/eigenfrequency-analysis).

Fig. 5 and Fig. 6 present the exponential damping curves and the spectral signal compositions for the tested top plates made of spruce and back plates made of maple, respectively. The values of the first natural frequency (f_0) and the damping factor (n) obtained for each tested violin plate are presented in Table 2. The average natural frequency ($\bar{f_0}$) and the average damping factor ($\bar{n}$) for each violin class are also presented in Table 2.

By analyzing the spectral composition of the spruce plates as compared to the maple plates, it can be noticed that the maple plates are much richer in frequencies than those of spruce. It turns out that from an acoustic point of view, the back plate contributes to the formation of harmonics and the considerable enrichment of the musical timbre (tone color) of the musical instrument.

From a technological and constructive point of view, the top plates have different thicknesses compared to the back ones. The thickness varies according to five zones, where zone 1 is the outmost region, around the edge (contour) and zone 5 is right in the center of the plate, being about 40% thicker than the contour. Being made of different species, there is a mass difference between the two plates (top / back) of 53-54% in the case of the master-class (A) and professional (B) violins and of 32-42% for the student-class (C) and school-class (D) violins.

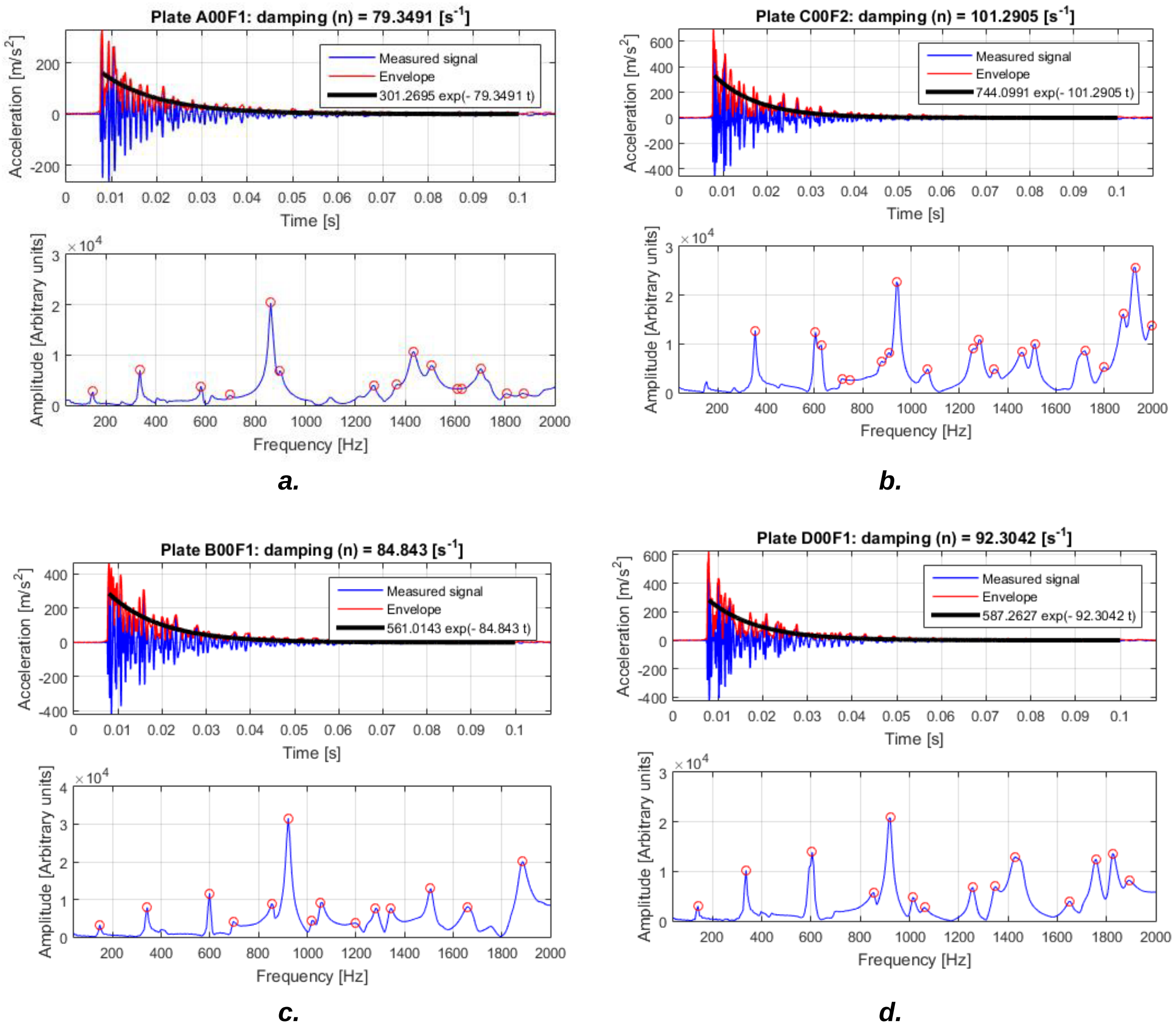

Fig. 5.
Exponential damping curve and spectral signal composition for top plates made of resonance spruce wood for: a – maestro violin ; b – professional violin; c – student violin; d - school violin

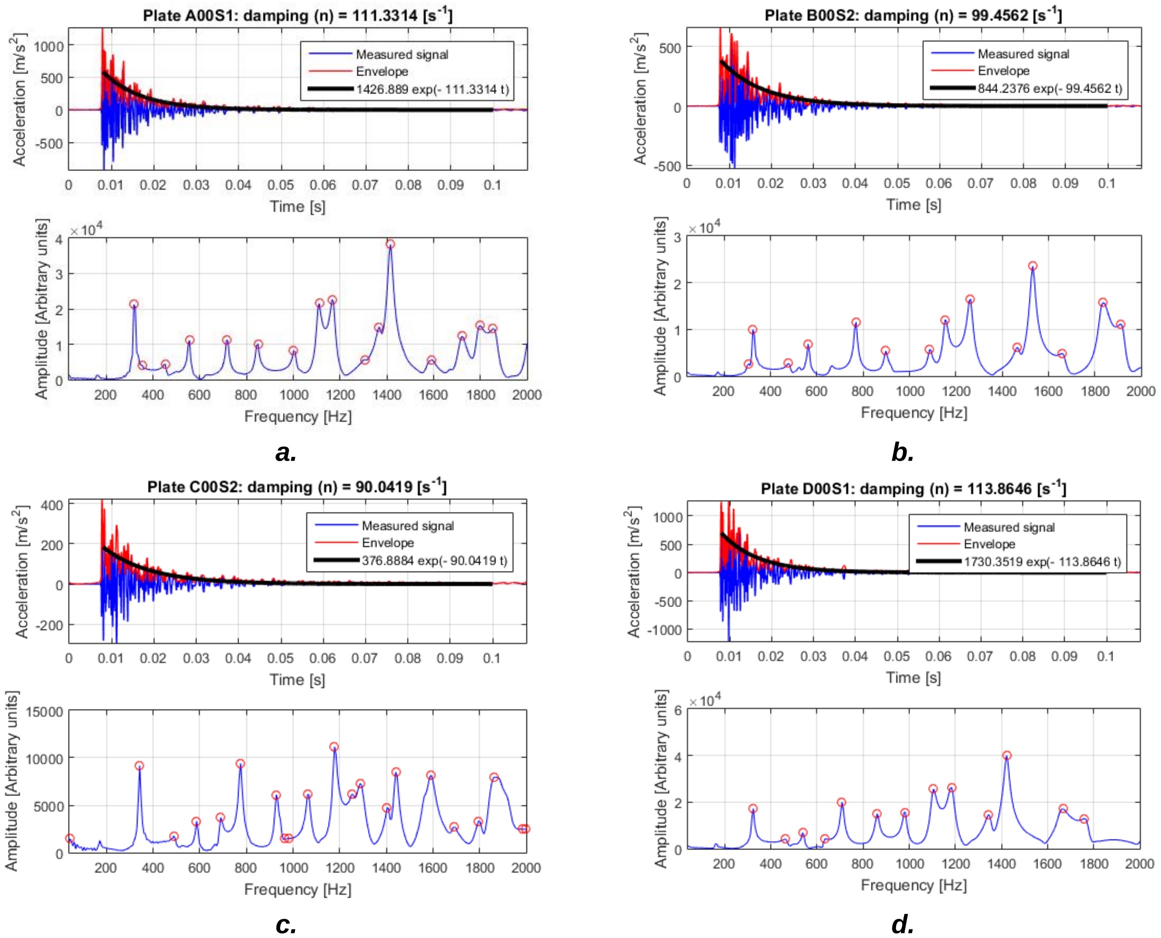

Fig. 6.
Exponential damping curve and spectral signal composition for back plates made of maple wood for: a – maestro violin ; b – professional violin; c – student violin; d - school violin

Table 2
The natural frequency and damping factor of top and back violin plates made of different wood species and wood assortments for different violin classes

Wood species	Sample code	Mass g	Thickness, mm					Natural frequency, f_0, Hz	Average $\bar{f}_0$, Hz	Damping factor n, s^{-1}	Average $\bar{n}$, s^{-1}
			Zone 1	Zone 2	Zone 3	Zone 4	Zone 5				
A-spruce	A00F1	76	2.5	2.7	2.9	3.2	3.5	146.48	146.48	79.349	78.83
	A00F2	85	2.5	2.7	2.9	3.2	3.5	146.48		78.302	
A-maple	A00S1	114	2.5	2.8	3	3.5	4.3	317.38	320.43	111.331	105.85
	A00S2	129	2.5	2.8	3	3.5	4.3	323.49		100.376	
B-spruce	B00F1	86	2.5	2.7	2.9	3.2	3.5	146.48	134.28	84.843	85.73
	B00F2	85	2.5	2.7	2.9	3.2	3.5	134.28		86.614	
B-maple	B00S1	136	2.5	2.8	3	3.5	4.3	347.90	323.49	109.31	104.38
	B00S2	131	2.5	2.8	3	3.5	4.3	323.49		99.456	
C-spruce	C00F1	93	2.5	2.7	2.9	3.2	3.5	140.38	146.49	106.98	104.13
	C00F2	90	2.5	2.7	2.9	3.2	3.5	152.60		101.29	
C-maple	C00S1	135	2.5	2.8	3	3.5	4.3	341.80	341.80	139.04	114.54
	C00S2	128	2.5	2.8	3	3.5	4.3	341.80		90.0419	
D-spruce	D00F1	86	2.5	2.7	2.9	3.2	3.5	140.38	134.28	92.3041	94.57
	D00F2	86	2.5	2.7	2.9	3.2	3.5	134.28		96.8283	
D-maple	D00S1	112	2.5	2.8	3	3.5	4.3	323.49	323.49	113.864	102.45
	D00S2	116	2.5	2.8	3	3.5	4.3	323.49		91.037	

The fundamental frequency also differs for the two types of plates: for the top plates made of resonance spruce, the average value was 140±6.4 Hz and for the back plates, the average value was 327±7.4 Hz.

Comparing the own frequencies of the plates for each quality class, it was established that for the master class violins the ratio is by 10% lower than for the other quality classes (Fig. 7).

From the viewpoint of the damping factor, it was established that with the decrease of the quality class of the violin, the ratio between the damping factors of the back plate and front plate, respectively, decreases (Fig. 8).

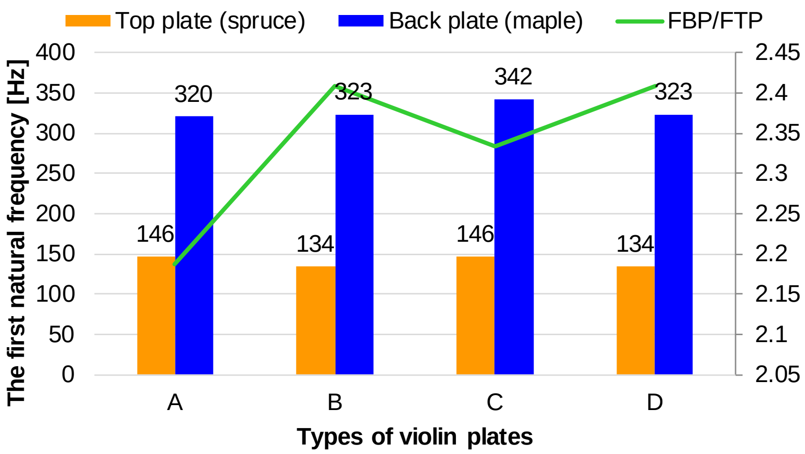

Fig. 7.
Comparison between the first natural frequencies obtained for the top plate made of spruce and the back plate made of maple, for violins belonging to different quality classes (A-maestro; B-professional; C-student; D-school)(FBP/FTP represents the ratio between the frequency of the back plate and that of the top plate).

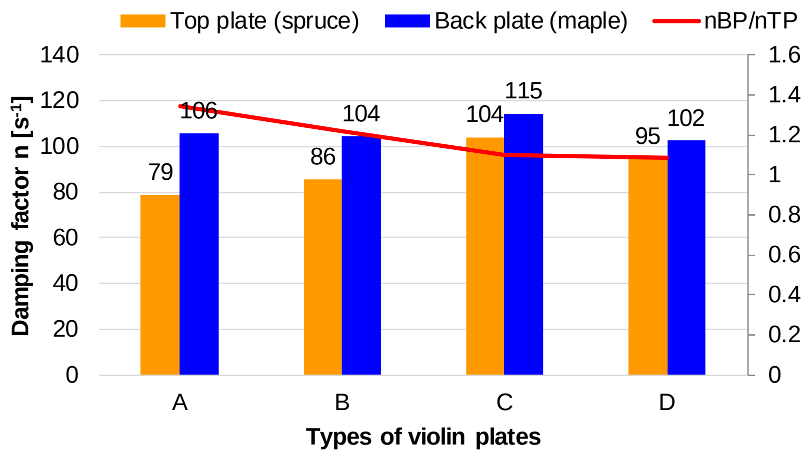

Fig. 8.
Comparison between the damping factors obtained for the top plate made of spruce and the back plate made of maple, for violins belonging to different quality classes (A-maestro; B-professional; C-student; D-school)(nBP/nTP represents the ratio between the damping factor of the back plate and that of the top plate).

CONCLUSIONS

The purpose of this experimental study was the modal analysis of the top and back plates for violins of different quality classes. The conclusions of the present research can be formulated as follows:

1. From the viewpoint of the structural characteristics of the resonance wood, the parameters that characterize each quality class of the wood used for violins type maestro (A), professional (B), student (C) and school (D), respectively, were established.

2. The experimental modal analysis showed that the spruce top plates have the first natural frequency about 2.5 times lower than the first natural frequency of the back plates (made of maple), regardless of the anatomical structure of the wood (which is different for the four quality classes).

3. The ratio between the natural frequency of the top plate and that of the back plate of a master-class violin is by 10% lower than for the other violin classes.

4. The damping factor turned out to be the lowest in the case of the spruce plate of the master-class violins (n = 79).

5. The ratio of the damping factors of the plates for master-class violins is about 27% higher than for the other violin classes.

6. The results are in good accordance with the ones provided by reference literature.

The research is going to be continued after pairing the top and back plates into violin bodies.

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REFERENCES

Albu CT (2010) Research on the characteristics of resonance spruce wood from Gurghiu River Basin in conjunction with the requirements of musical instruments industry. PhD Thesis, Transilvania University of Brașov, Romania, 365 p.

Bucur V (2006) Acoustics of Wood. 2nd edition. Springer Verlag Berlin Heidelberg

Bucur V (1987) Varieties of resonance wood and their elastic constants. J Catgut Acoust Soc 47:42−48.

Bucur V (1980) Anatomical structure and some acoustical properties of resonance wood. Catgut Acoust Soc Newslett 33:24−29.

Buen A (2005) Two models for predicting the violin timbre from the material properties of the top and back plates. Online at: http://home.online.no/~an-buen/CASJ%20Models%20for%20the%20violin%20sound%20spectrum.pdf

Dinulică F, Albu C, Borz SA, Vasilescu MM, Petriţan C (2015) Specific structural indexes for resonance Norway spruce wood used for violin manufacturing. **Bioresources** 10(4):7525-7543. DOI: 10.15376/biores.10.4.7525-7543

Dünnwald H (1991) Deduction of objective quality parameters on old and new violins. Catgut Acoust. Soc. J. (Series II) 1, 1–5.

Gough C (2015) Violin plate modes. J. Acoust. Soc. Am., 137(1):139-153.

Haines D (1979) On musical instrument wood. Catgut Acoust Soc Newsl 1(31):23−32.

Lomte CJ (2013) Vibration Analysis of Anisotropic Plates, Special Case: Violin. *ETD Archive*. 854. https://engagedscholarship.csuohio.edu/etdarchive/854

Molin NE, Lindgren LE, Jansson EV (1987) Parameters of violin plates and their influence of the plate modes, Journal of Catgut Acoustical Society 83(1):281–291.

Rocaboy F, Bucur V (1990) About the physical properties of wood of twentieth century violins. Catgut Acoust Soc J Ser 2 1(6):21−28.

Saitis Ch (2013) Evaluating violin quality: Player reliability and verbalization. A dissertation submitted to McGill University. Online at: http://www.music.mcgill.ca/caml/lib/exe/fetch.php?media=publications:phd_saitis_2013.pdf

Schelleng JC (1982) Wood for violins. Catgut Acoust Soc Newsl 37:8−19.

SR 1294:1993. Resinous roundwood for industrial purposes (in Romanian language)

*** https://www.comsol.com/multiphysics/eigenfrequency-analysis

*** https://www.physicscentral.com/