DREADNOUGHT GUITAR TOP PLATE INNOVATION

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Abstract: This paper describes the innovation of Dreadnought guitars, especially braces on top plate. The goal was to increase the dynamic range of the instruments, not only in strength but also in spectral spread. The prolongation of tones in the Sustain and Release phases was also important. Mechanical and acoustic properties of instruments from Furch Guitars' production were measured (Chladni figures, frequency response), numerical simulation of innovated top plate in program ANSYS was prepared (by the matrix) and the changes in organisation of ribs were proposed as following. The new samples of innovated Dreadnought guitars were produced by the factory, again measured, analysed and evaluated.

1. Introduction

The goal of the work was the innovation of Dreadnought guitars produced by Furch Guitars. The improvement wasn't just about getting a better timbre of the instrument compared to the competition, but also taking advantage of the construction improvements that the manufacturer has used in other types of its own guitars – for example, the proven braces and the convex tension of the resonant top plate in the OM (Orchestral model) guitars. At the same time, a number of sub-experiments were carried out: investigation of the properties of different resonance wood (for example spruces), different thicknesses of the resonant top plate, changes in the shape of ribs (bracing), differently tensioned and pressure-transmitting strings, etc.

2. Plucking point on the string

The ideal string is an almost perfect oscillator due to its one-dimensional character. When properly excited, it can generate an almost pure harmonic spectrum composed from harmonic components. [5] The quality of the spectrum (spectral components, spread, slope, spectral centroid, etc.) depends on the mechanical properties of the string: string diameter, string length, material density, modulus of elasticity, tensile strength, etc. These properties were preserved as constants during the measurements due to using the same strings and the same length instruments from the bridge to the nut (scales length/mensura).

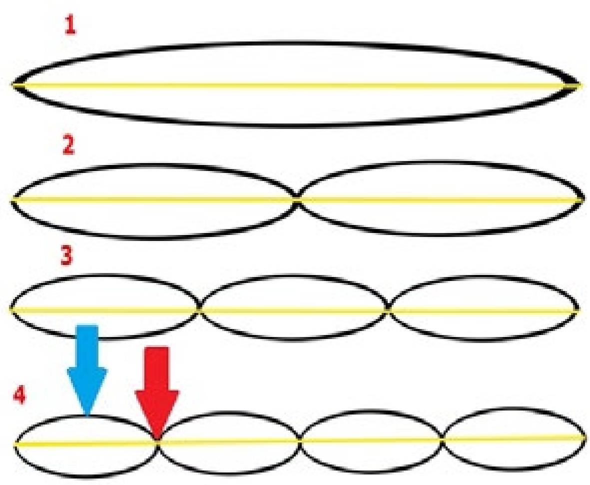


Fig. 1: Plucking into anti-node (desirable-blue arrow) and into node (undesirable-red arrow)

The bigger problem in the measurement stages was to maintain the same excitation – plucking the string as similar as possible. The tones were excited by a guitarist using the same pick, and especially the same place of strumming: about one-ninth of the string away from the bridge. The important thing was to hit the anti-node in one-ninth as much as possible, not to hit a node, when every 9th harmonic component and its successive multiples (18th, 27th, etc.) would be missing, see Fig. 1. [7]

Although the player tried to strum as technically as possible, it became more difficult to maintain the same strength (pressure at the area of the pick) of strumming, and especially the excitation time.

3. The guitar body: dimension, braces

We can think of the guitar as a system of coupled vibrators. The main oscillators – the strings that are plucked with fingers or a pick – emit only a small amount of their own energy into the surrounding air. However, the strings transmit their majority of vibrations to the bridge, which spreads them laterally and longitudinally to the top plate, on the bodysides and then into the complete body of the instrument. The significantly oscillating top plate will also radiate its energy to the air inside the body. The compressed air partially vibrates the ribs on the top plate and, more strongly, the entire back-plate. In total, the guitar therefore radiates energy (sound aura) mainly through the soundboards and the round sound hole. The guitar body is thus the alpha and omega of a musical instrument.

3. 1. Transfer of vibrations to the top plate

The quality of the strings and the way how the bridge transmits the vibrations from the strings to the top plate is crucial to the creation of the so-called vibrational modes on the top plate. Simply put, it depends on whether the bridge "swings" from left to right and transmits more significant energy longitudinally, whether it sways from back to front and thus strengthens oscillations in the transverse direction, or whether the density and tension of the strings are more compressive - fixing the bridge and the type of strumming roughly succeeds to equalize both directions and thus induce the so-called static transfer of energy. [2]

In the case of nylon strings on the so-called Spanish guitar, the bridge transmits vibrations transversely, i.e., in the direction of the strings. In guitars with steel strings (which is also the case with the innovative Dreadnought guitar), due to the higher Young's modulus of elasticity of steel (about 40 times greater than that of nylon), the static string tension increases, and thus the longitudinal and transverse forces are equalized.

If the guitarist uses two strokes called apoyando and tirando – static strumming, which would not unduly deflect the string (not excessively perpendicular, not excessively longitudinal or torsional), then the required static - uniform transfer from the bridge to the top plate will be preserved. [2]

Fig 2: Dreadnought top plate braces

Two types of wooden resonators support different frequency bands: the soundboard, actually a two-mass vibrating system with two sub-oscillating parts (bridge and top plate) boosts the treble. Thanks to the different types of braces, other single vibration modes arise on it.

The bottom-plate then strengthens the lower bands in the spectrum.

3. 2. Types of braces

The traditional Torres, Bouchet or Ramirez fan-shaped braces covering a larger part of the top plate is based on trapezoidal open shapes, see Fig. 3 a–c. It thus creates more continuous and flatter formants in the spectrum. Rossing's crossed bracing (also the case of the innovative Dreadnought guitar, see Fig. 2) works with both parallel and trapezoidal, but mostly closed shapes, see Fig. 3 d. [2] Formants are, as a result narrow and reinforcing more pronounced frequency bands in the middle and trebles.

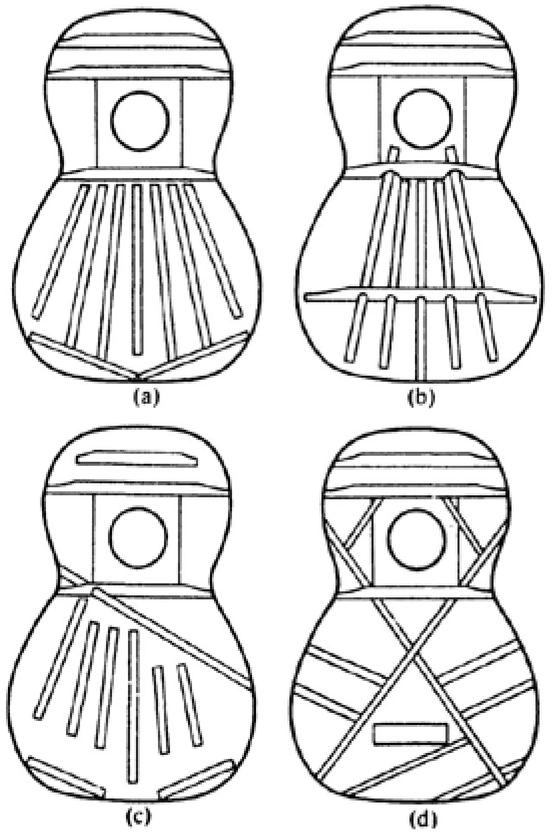


Fig. 3: Braces a) Torres, b) Bouchet, c) Ramirez and d) Rossing

The second, this time three-mass vibration system consists of the top plate and the following two branches. In the first branch, the top plate transfers energy via air into inside the body and it radiates out through the sound hole. In the second branch, the top plate transfers energy to the ribs, which then transmit their vibrations to the bottom plate. In the system, due to the different speed of sound in different types of wood (resonant spruce, maple, etc.) and in the air, the desired summation of waves in phases occurs (the top and bottom plates oscillate in harmony), but also unwanted "antipolarities" of waves occur, when delayed waves at the corresponding frequencies (wavelengths) disturb the movement (vibration) of the top and bottom plates.

4. Soundboard upgrade requirements

The purpose of the innovation was to fill the breaks between the formants in the spectrum (even out of the resonance curves), to make the Dreadnought from Furch Guitars sharper and fuller in timbre. Related to this was the increase in the dynamic range of the instrument (by the difference between pp to ff dynamic levels), not only in strength but also in spectrum width. The prolongation of tones in the Sustain and Release phases was also important.

First, it was necessary to measure the mechanical and acoustic properties of guitars from Furch Guitars' own production, as well as guitars from competitors. The vibration modes of selected guitars were identified using the SWEEP method and the identification of Chladni patterns. Sound samples of these guitars were recorded in the anechoic chamber of Brno University of Technology. (Fig. 4) and their spectral analysis was performed. A series of spectrographs and spectrograms served as output for comparison. Using them, we determined the death bands (breaks) in the spectrum, which needed to be strengthened by the innovative soundboard.

Fig. 4: Measurement of spectra and sound radiation in the anechoic room of Brno University of Technology

Two types of the innovative top plate were modeled in the ANSYS program – with trapezoidal and exponentially built braces. By simulating removing or moving the ribs, new vibration modes and their relation to the spectrum were estimated.

According to new designs, Furch Guitars produced only top soundboards with innovative braces. These boards were mechanically and acoustically measured and adjusted. After that, Furch Guitars produced complete upgrade Dreadnought guitars: DRMI with lighter improvement and DRVI more experimental. We then acoustically measured them again in an anechoic room and compared their properties with the competition and Furch Guitars.

5. Measurement of guitars that will be upgrated

5. 1. Chladni figures

When measuring, we used the methods described in the literature of Václav Syrový. [10] The first method was generating Chladni figures. The measured part of the instrument, in our case the top plate of an acoustic guitar, was sprinkled by granular powder, vibrated by a generator that is located near it and excites a harmonic signal of a specified frequency and volume. Due to the excitation, the top plate starts resonating together with the generator at the given frequency and creates anti-nodes and nodes on the flat - so-called mechanical resonance patterns corresponding to the respective frequency. The powder moves from the vibrating places (anti-nodes) to the nonvibrating places (nodes), see Fig. 5, and thanks to this it is possible to observe the behavior of the patterns/resonance modes, see Fig. 6. The shape and area of the mechanical figure is evaluated and related to the spectrum. [10]

5. 2. Sweep method

The second method, the so-called "Sweep", was used to obtain the frequency response of the measured soundboard. The top plate is excited by a retuned harmonic signal with the help of a generator. Thanks to smooth retuning, it is possible to observe a wider frequency picture, not just one frequency. The frequency response was recorded by a sensor, either in contact or in the far field. Usually at distance of 1 meter from the sound source. The signal captured by the sensor or microphone is saved into the program. We then obtain the audio file from the recording program, while applying the FFT we calculate the module characteristic and frequency response.

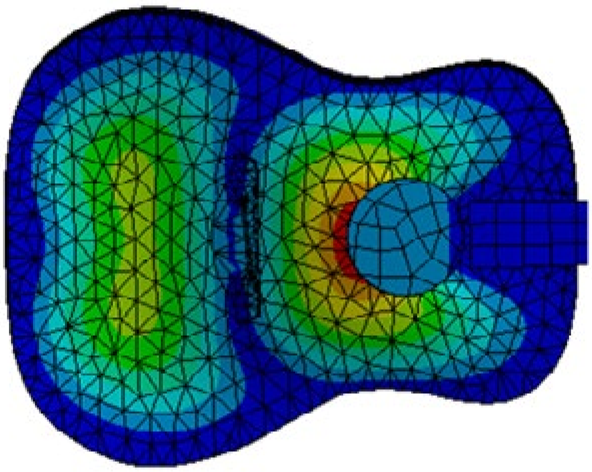


Fig. 5: Chladni patterns

Fig. 6: Guitar resonance mode with ANSYS braces

Visualization using FFT and STFT analysis was used to evaluate the measured data. The calculations were performed in the Matlab program.

FFT (Fast Fourier Transform) is an algorithm used to convert a signal from the time domain to the frequency domain. Before the FFT calculation itself, it was necessary to choose the length of the FFT, which affects the frequency resolution of the resulting spectrum (to achieve optimal performance of the algorithm, it should be a power of 2) and apply a time window for weighting. A Hanning window was used in this work. STFT (Short Time Fourier Transform) is simply an FFT algorithm, which additionally divides the signal into overlapping sections of length N samples before its actual application. According to the length of the samples and the overlapping window, which usually takes half the value of the length of the samples.

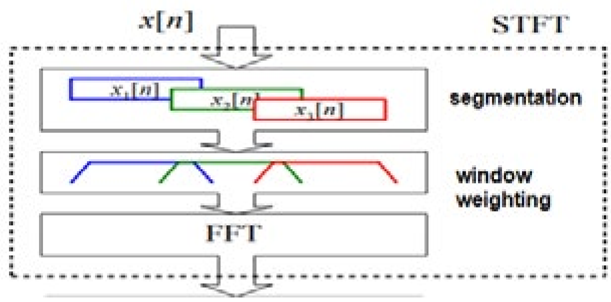
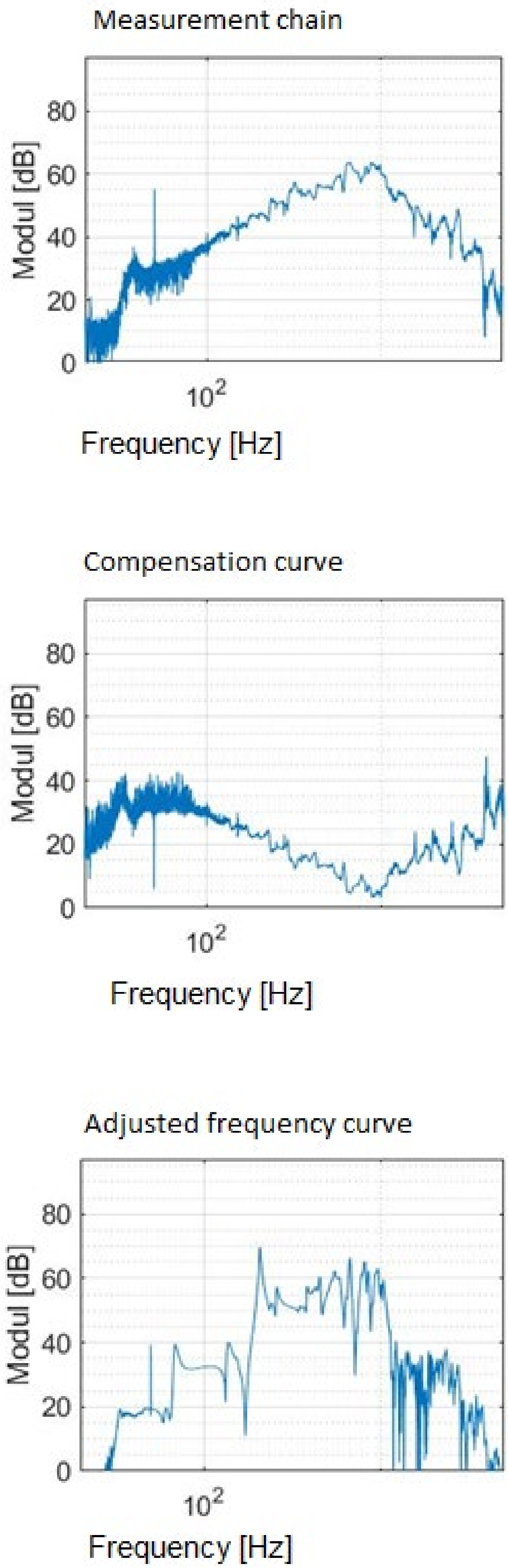


Fig. 7: Short Time Fourier Transform

In order for the display of the frequency response to be exact as possible, it is necessary to subtract the frequency response of the own measurement chain from the obtained frequency response. [10]. See figures 7 and 8.



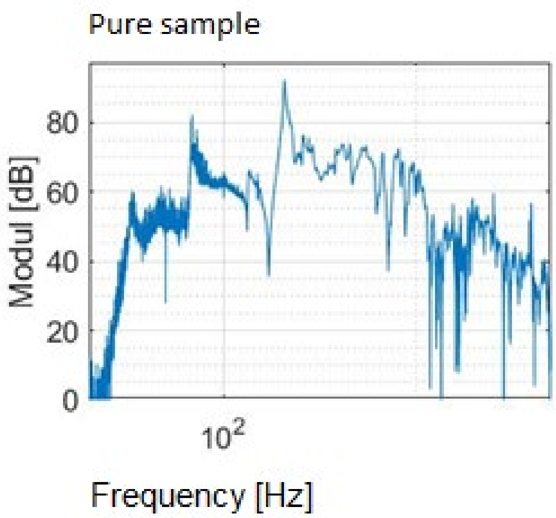


Fig. 8: Frequency response of the top plate

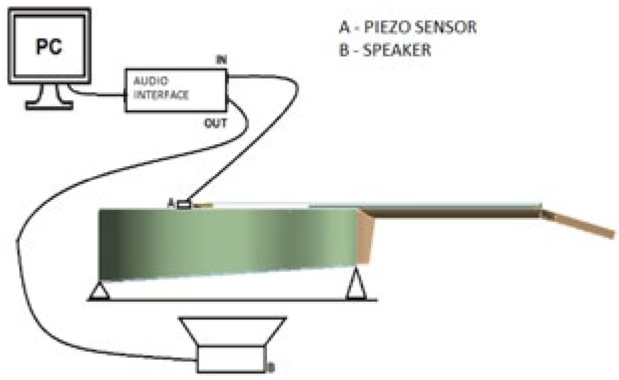


Fig. 9: Simple circuit diagram

The Chladni patterns method provides detailed information on mechanical parameters, but its acquisition is more time-consuming (each resonance mode must be generated separately). The sweep method, on the other hand, takes only a few seconds, but it does not provide detailed information about the mechanical properties, it only provides information at which frequencies modes occur and what power they generate. [10]

5. 3. Combination of both methods

By combining both methods, we get a more comprehensive view. In addition, by checking, during which we dampen the identified mechanical resonance modes on the top plate, we confirm whether they really correspond to the frequencies or frequency bands in the spectrum.

It is possible to find a number of formant regions on an acoustic guitar. The well-known formants are the resonance modes of the neck, top plate, bottom plate, sides, acoustic guitar body, bridge, and Helmholtz resonance. Some formant regions match the dynamic ADSR tone envelope of the string, and some have their own dynamic and own behavior. [10]

Both measurements found dead spots on the top of the acoustic guitar, and the braces in that area were adjusted to eliminate breaks in the spectrum as much as possible. [10]

6. Computer simulation

The guitar was simulated in the ANSYS ACADEMIC 2020 program dealing with physics problems that are solved using the finite element method. The program was used to calculate the modes and frequency response on a single top plate with and without ribs and on the complete model with and without string tension. [3]

The simulation in the ANSYS program consists of 3 main parts following each other:

Preprocessing
Solution
Post processing

6. 1. Data entry

In the Preprocessing section, input data is entered, i.e., the physical properties of the materials (wood, air, string, etc.). This is followed by the modelling of the guitar, which consists of assembling the individual parts and determining the connections between them. Input data is assigned to individual parts of the model using coordinate orientation. The finished model is analysed and the so-called finite element network is created according to the user's requirements.

The calculation is handled by the Solution block, which allows to specify conditions such as initial positions, force, damping, tension, fixation, and many others. The initial conditions are refined according to the needs of simulation and analysis.

For the computer simulation of top plate modes, we chose the so-called modal analysis imitating modes. It can be compared to the method of Chladni figures.

Harmonic analysis was used to calculate the frequency response. When setting it up, it is necessary to specify which signal should be used for the calculation, whether logarithmically or linearly retuned and by what steps. If we insert the frequencies of top plate modes obtained in the modal analysis into the simulation, we speed up the complete process. The harmonic analysis can be similarly compared to the Sweep method. Finally, it is necessary to instruct the program to what extent and whether to export the result and how to display the result. Finalization is dealt with in the Postprocessing section. [1]

The simulation methods of modal and harmonic analysis are actually a subset of the so-called structural analysis. The calculation of structural analysis differential equations is applied separately to each element of the finite element mesh created in the Preprocessing section. The data matrix is decomposed into a finite number of linear equations. Continuous deformation is obtained by approximating the deformation of each element. In general, the formula used to calculate deformation in structural analysis is: [1,3]

$$[M]\{u\} + [K]\{u\} + [C]\{u\} = \{F\} \qquad (1)$$

where [M] is the structural mass matrix, [K] is the structural damping matrix, [C] is the structural stiffness matrix, $\{\ddot{u}\}$ is the nodal acceleration vector, $\{\dot{u}\}$ is the nodal velocity vector, {u} is the nodal displacement vector, and {F} is the resulting strain vector.

To construct the modal analysis, we used formula (1). The calculation is intended only for finding resonance modes of the body, i.e., it does not take into account the deformation of the body, and is given by the relation:

$$[M]\{u\} + [C]\{u\} = \{0\} \qquad (2)$$

The position vector can be expressed as:

$$\{u\} = \{a\}_n \cos(\omega_n t) \qquad (3)$$

where {a} expresses the *n*-th amplitude of the *n*-th angular frequency ω at time *t.*

6. 2. Matrices

All the formulas presented here can be further changed according to the initial conditions and the chosen type of displayed solution. The weight matrix [M] is calculated by the program according to the dimensions of the modeled part and the input data attached to it. The damping matrix [K] can be already fixed in the input data or additionally added in the Solution section. For the calculation, it was necessary to supply other input data that contained material properties such as density, speed of sound propagation, strength, and elasticity of the material. In the computer simulation of the upgraded acoustic guitar, the input data had to be entered for an orthotropic material, and therefore the stiffness matrix [C] and the compliance matrix [D] (with the equation for calculating the deformation according to Hooke's law) had to be created, see (4),

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ 2\varepsilon_{yz} \\ 2\varepsilon_{zx} \\ 2\varepsilon_{xy} \end{bmatrix} = \begin{bmatrix} \frac{1}{E_x} & \frac{-\mu_{xy}}{E_y} & \frac{-\mu_{xz}}{E_z} & 0 & 0 & 0 \\ \frac{-\mu_{yx}}{E_x} & \frac{1}{E_y} & \frac{-\mu_{yz}}{E_z} & 0 & 0 & 0 \\ \frac{-\mu_{zx}}{E_x} & \frac{-\mu_{zy}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{xz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xy}} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{yz} \\ \sigma_{zx} \\ \sigma_{xy} \end{bmatrix} \qquad (4)$$

where *E* is the Young's modulus of elasticity in tension, *G* is the Young's modulus of elasticity in shear, μ is the Poisson's number, ε is the relative strain, and σ is the tensile stress, all depending on the (*x, y*, and *z*) direction. [1,3]

7. Improvement: deflection of ribs inappropriately damping the required modes

First, we modeled a guitar intended for innovation on the computer. It was appropriate that it be as corresponding as possible to the original. Therefore, all parts of the default physical guitar had to be carefully measured: the body and every single rib. The complete computer model contained over 700 construction points, see Fig. 10 and, for example, the top plate itself was composed of 250 edges. Furthermore, it was necessary to create input data for individual parts of the module. Since the ANSYS program does not contain input information about the given type of wood in its database.

For the purpose of simulation, the properties of the wood material were experimentally measured and averaged on 10 samples from each type of wood that Furch Guitars normally uses to make its instruments. See (5): Table of material properties [1,3]

Material properties		Part			
		Top plate	Bodysides, back plate, neck	Braces	Fingerboard and bridge
		Material			
		Resonant spruce AA	Rosewood	Czech spruce	Ebony
Density	ρ [kg.m⁻³]	418	717	576	1288
Speed of sound propagation	v_x [m.s⁻¹]	4950	4353	5116	4330
	v_y [m.s⁻¹]	1335	1963	1220	1740
Young's modulus of elasticity in tension	E_x [GPa]	10,2	13,6	15,1	24,2
	E_y [GPa]	0,7	2,8	1,5	3,9
	E_z [GPa]	0,4	0,4	0,11	4,1
Poisson's number	Pr_{xy} [-]	0,4	0,32	0,37	0,37
	Pr_{yz} [-]	0,4	0,21	0,44	0,43
	Pr_{xz} [-]	0,5	0,15	0,46	0,47
Young's modulus of elasticity in shear	G_{xy} [GPa]	1,3	2,7	0,67	4,3
	G_{yz} [GPa]	0,08	0,17	0,06	1,8
	G_{xz} [GPa]	0,3	0,38	0,57	4,5
Acoustic constant	K_x [-]	11,8	6,1	8,9	3,4
Acoustic wave resistance	Z_x [GPa.s.m⁻¹]	2,1	3,1	2,9	5,5

Tab. 1: Table – Material properties

It was necessary to measure these properties on the materials from which the Dreadnought guitar is made. The measured properties were inserted into the compliance matrix [D]. As follows from relation (5), the stiffness matrix [C] is the inverse of the compliance matrix [D].

[D] = [C]-1 (5)

The input wood data from the internet database of wood material properties was also used for the control.

Fig. 10: Complete acoustic guitar model

After entering all the necessary data, the simulation was started. The aim was also to detect by computer places with minimal or no resonance. The computer model matched the physical measurements (Chladni patterns and frequency response) to a high degree. In order to eliminate these "deaf" breaks in resonance, we proposed changes in braces: the deflection of the ribs inappropriately damping the necessary vibration surfaces to the places of the most frequent nodes or even the eventual removal of the ribs.

We also decided on an experimental innovation of braces and created exponential braces, Fig. 15, which would be placed in positions where nodal points are most often located.

8. Production of pilot physical instruments and their measurement

The company Furch Guitars always produced two pairs of instruments for both the first DRMI and the second DRVI innovation, a total of four test pieces. We decided to use pairs so that we could verify the given innovation on at least two guitars and find out to what extent the result is the same or different. Differences may have occurred due to the specific properties of the wood used in production.

Fig. 11: Pilot upgraded DRMI and DRVI guitars

For the upgraded pairs, we measured the complete frequency response, for the selected tones the quality of the spectrum (number of components and their behavior over time), the ADSR curve and we also compared some Chladni figures.

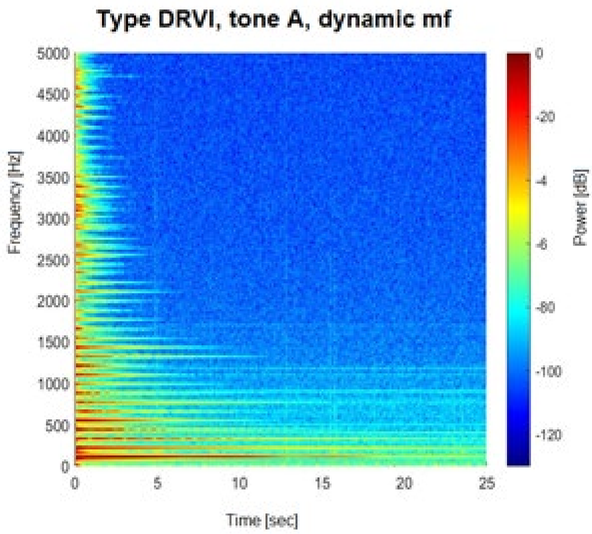
The upgraded guitars were compared to Furch Guitars own Dreadnought line, other Furch Guitars lines (orchestral models) and competitive guitars.

9. Evaluation

In this part of the article, we will briefly present the measurement results of all innovative braces.

9. 1. Changes in spectrum

Fig. 12 shows 3 spectrograms of the tone "A" in mf dynamics relating to three guitars: the lighter DRMI innovation, the larger DRVI innovation and the original DR innovated instrument. At first glance, it is clear in the case of both innovations, that the resonator will support harmonic components for a longer period of time. The higher harmonic components of both innovative instruments sound up to 5 seconds longer on average, so the guitar sings much more prominently (it resembles, for example, a woodwind instrument with a sustained tone). Furthermore, it can be observed in the spectrogram of the original instrument that deaf breaks (teeth) are created in the spectrum on the 6th, 7th, 13th, 14th, etc. harmonic components. The spectrum of innovative instruments does not lack these harmonic components and is generally more balanced and colorful in timbre. Similar differences between the original instrument and the upgraded instruments were observed on multiple tones examined at different dynamics. [3]



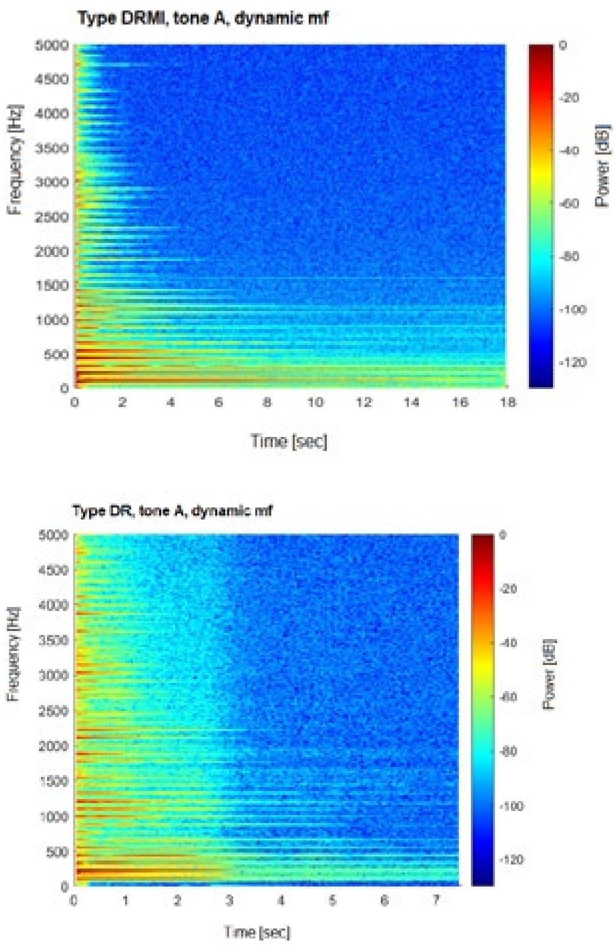


Fig. 12: Comparison of acoustic guitars before and after innovation

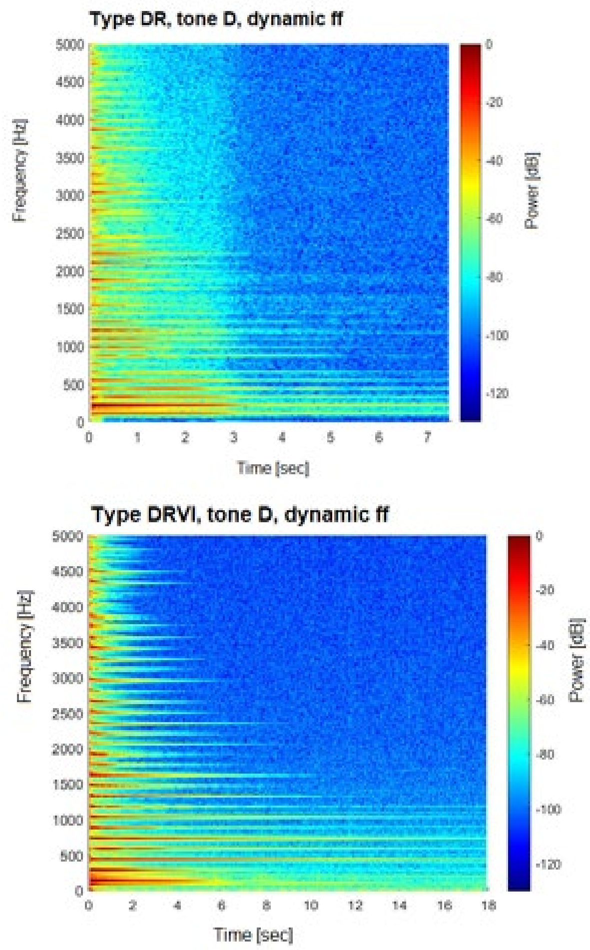


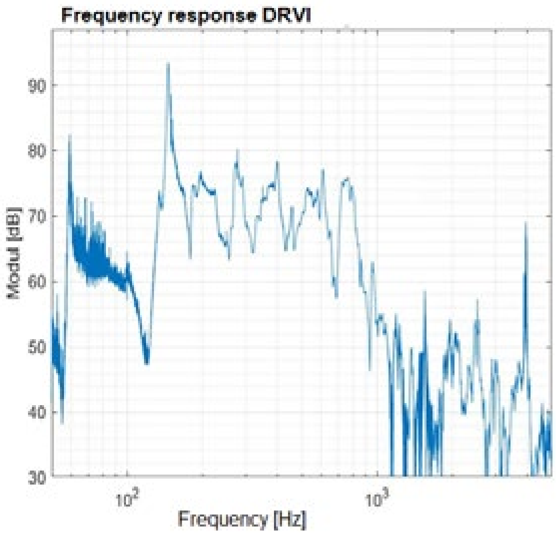
Fig. 13: Comparison of DRMI and DRVI upgraded guitars

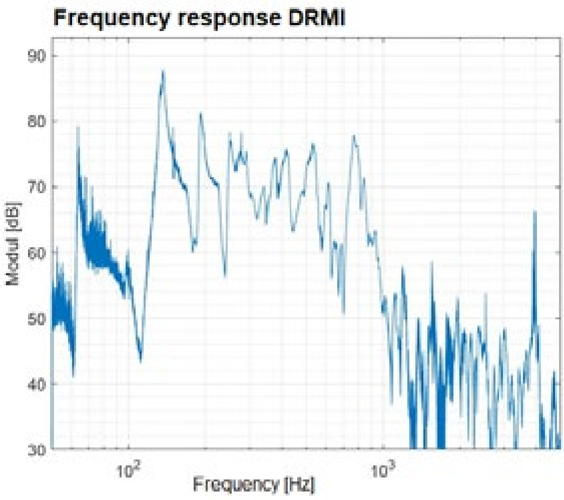
The differences between the DRMI and DRVI innovations are shown in Fig. 13. Both guitars play the note "D" on the open string in the ff dynamics. The guitar with the DRVI innovation features a longer duration of all generated harmonic components, up to 6s more than the DRMI innovation. At the same time, its spectrum is richer in timbre.

The resonance of the top plate works much stronger with the DRVI guitar, while the DRMI has a significantly weaker one. It can also be observed that the harmonic components of the DRVI guitar show more power, especially at higher frequencies. The DRMI is poorer in timbre, for example in the area from 500 Hz to 1.5 kHz, the harmonic components are significantly weaker than in the DRVI guitar. The similarity of all these properties was also observed on other samples. [3]

9. 2. Changes in frequency response

The frequency response of the top plates is shown in Fig. 14. When compared with the model intended for innovation, we discovered a newly created resonance mode at a frequency of 150 Hz at the top plate of the DRMI. The same mod has also been added to the top DRVI board. Compared to DR, the DRMI top plate was boosted in terms of performance at higher frequencies, but a much more significant overall boost can be observed in the DRVI top plate. The image of both top plate modes is very similar. Based on the comparison of the frequency response, it can be argued that both innovations lead to the correct result. [3]





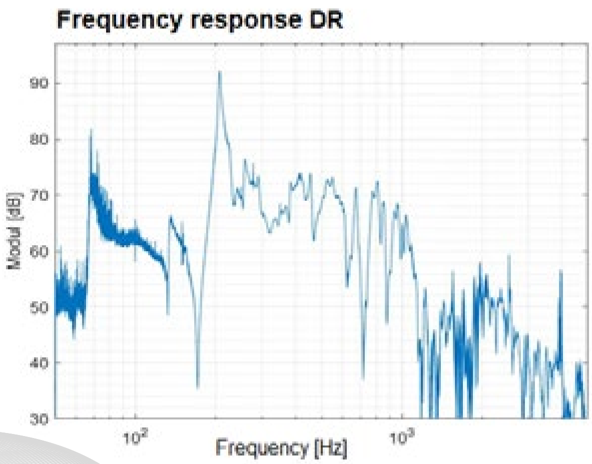


Fig. 14: Comparison of the frequency response of the top plates before and after the innovation

9. 3. Experimental braces

Experimental braces were so far been simulated only in the ANSYS program. A physical sample has not been produced, and therefore not subjected to physical measurement. In the simulation, it can be observed that the locations of the created nodes correspond almost exactly to the positions where the ribs are located. The vibrating surfaces (patterns) on the experimental rib are reinforced in most areas and are not as "fused" as in the parallel ribs. This should result in more separated and readable formant regions in the spectrum. The vibration modes show a higher elasticity especially in the lower (bridge) surface of the top plate than when using conventional braces, see Fig. 15. The lower surface of the experimental braces contains the largest number of vibrational modes, which will color-enhance the center of the spectrum. It can therefore be judged that experimental braces are very likely to lead to the correct result. [1]¨

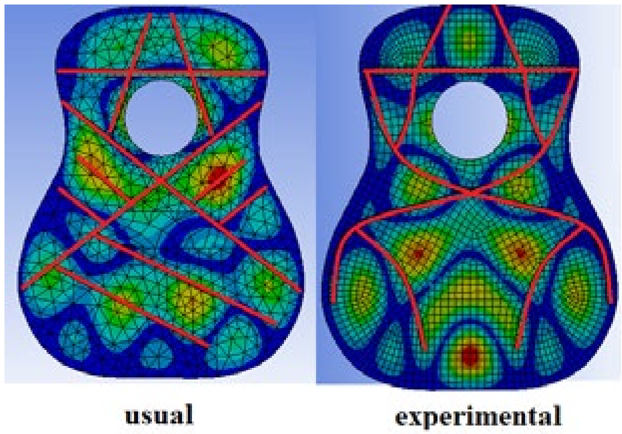


Fig. 15: Top plate modes up to 1 kHz in conventional and experimental braces

10. Discussion and conclusion

According to the manufacturer Furch Guitars, the second "daring" DRVI innovation came out sounding more interesting than the first, which focused only on filling the death bands in the spectrum. They appreciate the instrument as sounding more colorful and dynamic. One thing is, of course, the rational technical improvement of the instrument, and another is how the users - guitarists will accept the new sound. Furch Guitars are planning to launch an innovative product on the market, and we have to wait for a reaction of the musicians.

With every innovation and measurement, other questions will naturally arise regarding the accuracy of the measurement and the functionality of the innovation. In the future, it will be important to generate strumming with a mechanical hand to ensure as similar a tone excitation as possible.

A separate top plate and another one woven into sides and connected to the body behave differently. Both during simulation and in the finished product.

For the future, it would be advisable to simulate the complete body in a computer program. A more detailed measurement of the physical top plate embedded in the body can then be realized by gradually sinking the tool into the fixation substrate (e.g. sand) and observing how its parameters change. This type of measurement also offers the possibility to obtain additional data.

And of course, the important question is how a physical guitar with experimental, exponential braces can sound.

References:

[1] ANSYS Theory Reference. 001242. Eleventh Edition. SAS IP, Inc. 1999, Eleventh Edition(001242).

[2] FLETCHER, Neville H., ROSSING, Thomas D. The Physics of Musical Instruments, Second Edition, Springer, © 1998 Springer Science+ Business Media New York Originally published by Springer Science+ Business Media, Inc. in 1998 Softcover reprint of the hardcover 2nd edition 1998, ISBN 978-1-4419-3120-7

[3] HOFFMAN, Pavel. Inovace žebroví kytary Dreadnought [online]. Brno, 2021 [cit. 2021-05-20]. Dostupné z: https://www.vutbr.cz/studenti/zav-prace/detail/133467. Diplomová práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav telekomunikací.

[4] https://furchguitars.com/en/

[5] CHAIGNE, Antoine, KERGOMARD Jean. Acoustics of Musical Instrument, Springer-Verlag New York 2016, 2364-4923

[6] Mathworks. Mathworks [online], [cit. 2023-07-17]. Dostupné z: https://uk.mathworks.com

[7] KOENING, D.V. Spectral analysis of musical sounds with emphasis on the piano. Oxford: Oxford University Press, 2015. ISBN 978-0-19-872290-8

[8] MEYER, Jürgen. Akustik und musikalische Aufführungspraxis, 4. überarbeitete Auflage, Verlag Erwin Bochinsky, Frankfurt am Main 1999, ISBN 3-923639-01-5

[9] SCHIMMEL, Jiří. Analýza zvuku, prezentace k předmětu Měření v audio technice a akustice. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav telekomunikací. Brno, 2021

[10] SYROVÝ, Václav. Hudební akustika. 3., dopl. vyd. V Praze: Akademie múzických umění, 2013. Akustická knihovna Zvukového studia Hudební fakulty AMU. ISBN 978-80-7331-297-8

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acoustic, anechoic chambre, braces, compliance matrix, computer simulation, dreadnought guitar, frequency response, fast Fourier transform, Furch guitars, experiment, Chladni figures, nodal acceleration vector, nodal displacement vector, nodal velocity vector, measurement, Poisson's number, relative strain, resonance modes, resulting strain vector, short time Fourier transform, soundboard, spectrograph, spectrogram, spectrum, stiffness matrix, structural damping matrix, structural mass matrix, structural stiffness matrix, SWEEP method, tensile stress, top plate, Young's modulus of elasticity, vibration

About authors

At Brno University of Technology, **MgA. et Mgr. Ondřej Jirásek, Ph.D.** lectures and leads exercises on Acoustics of musical instruments and the human voice, Instrumentation, Studio equipment, Sound for multimedia, etc. At Janáček Academy of Music and Performing Arts, he teaches electro-acoustic music and other subjects. He also writes music, occasionally conducts and plays in bands, and is active in his recording studio. He is the author of approximately 12 books (e. g. on the use of computers in music) and 400 professional and popular articles on the subject of music, musical acoustics, home studio, arranging, mixing music.

Pavel Hoffman, Ing., is a research and development engineer with a focus on acoustic guitars. He spent 3 years of his career doing extensive research and development at Furch Guitars, a leading guitar manufacturer based in Velké Němčice. He is currently focused on research into the automated sorting of materials based on their specific properties. Its main goal is to understand the behavior of various guitar components and assign them to certain parts of an acoustic guitar based on their material characteristics. In this way, he seeks to maximize their effectiveness and predict how they will contribute to the resonance of a particular type of guitar body. Through his outstanding work, he has demonstrated a deep commitment to advancing the field of acoustic guitar manufacturing. His research not only increases the precision and quality of guitar construction, but also provides valuable insights into optimizing resonance and tonal properties.