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A new concept for string-instrument sound board : the splitting board

Charles Besnainou (1), Joël Frelat (1) and Kurijn Buys (2)

(1) Institut JeanLeRond d'Alembert, Université Pierre & Marie Curie, 4 place Jussieu 75005 Paris, France
(2) ATIAM, LAM-IJLRDA, 11 rue de Lourmel 75015, Paris, France

ABSTRACT

All strings instruments function in the same way : a driving system –the strings–coupled with a radiating surface –the-soundboard– via an intermediating element –the bridge. The acoustic qualities are determined by the particular organization of these three elements: Exciter - Coupling - Resonator. The art of instrument making is in the optimum transformation from mechanical energy of the strings into radiating acoustical energy. Holding all other parameters constant between two given instruments, this radiated energy depends on both the modal shape of the eigenmodes of the soundboard and the location of coupling. There is always a compromise between different parts of the spectrum depending on the eigenmodes that radiate efficiently and those that radiate weakly. Indeed, whenever eigenmodes are symmetrical the far-field radiation for even-modes reaches its minimum by the destructive interference of its acoustic sources. On the other hand, if the modal geometry is odd, the radiation is maximized. Taking this into account, instrument makers working to create functional asymmetries such as all modes radiate as close to their respective maxima as possible. Should they arrive at a spectrum that lacks a given eigenmode of vibration, the structure does not radiate. The perceptual signature of a given instrument, therefore, depends on the adjustment of maxima and minima of radiation. A new manner of radiation optimization is possible by splitting the radiating element : the soundboard. We can first, by adjusting the modal properties of each of the aforementioned elements, ensure that the maximum radiation of an element corresponds to the minimum of the other element. As a result, a more homogeneous acoustical response is achieved. In addition, by judiciously choosing the location of coupling, we can systematically create asymmetries in the geometry of eigenmodes. As a consequence, the far-field radiation is considerably improved. Furthermore, by coupling these split elements, an exchange of energy is carried out in real time, thereby enriching the resultant sound. So, by assigning to each soundboard component a dedicated part of the spectrum to be radiated, a new paradigm of sound optimization is arrived upon. This paper presents a model and some measurements that endeavor to substantiate the model discussed above. A violin and a guitar will be shown and played. (patents pending)

INTRODUCTION

The instruments makers are facing a double bind : on one hand ensure the contunuity of a sound paradigm, closely linked to culture and on the other hand to carry out best radiation efficiency of the instruments they create.

All strings instruments function in the same way : a driving system –the strings–coupled with a radiating surface –the-soundboard– via an intermediating element –the bridge. The acoustic qualities are determined by the particular organization of these three elements: Exciter - Coupling - Resonator. Thus, the optimal transformation from mechanical energy of the strings into radiating acoustical energy depends essentially on both the modal shape of the eigenmodes of the soundboard and the location of coupling.

A new way of radiation optimization is possible by splitting the radiating element : the soundboard. We can first, by adjusting the modal properties of each of the aforementioned elements, ensure that the maximum radiation of an element corresponds to the minimum of the other element, and then maximize the radiation.

In order to check the validity of the previous assumptions, we conducted a modelling of the problem, and at the same time we carry out an experiment with a real guitar specifically designed to test the modelling results.

MODELLING

In order to validate and quantify the changes induced by the new geometry proposed, we achieved a finite elements calculus on a basic model. We used the finite element software CAST3M developed by CEA in France [1]. We started from the template of a classical guitar that we have drastkly simplified, ie : the thickness of the sound board is constant, without bracing and with boundary conditions clamped on the edge ribs and at the finger board to the rosette level. The finite element model use a « DKT » (discrete kirchhoff triangle). The behaviour is elastic and anisotropic with material properties of « spruce».

The model has 5184 elements, 2709 knots and then 2709x6 =16254 degrees of freedom with the following mechanical constants of spruce : E_L = 10.5 GPa ; E_R = 0.47 GPa ; density 460 kg/m3 ; shear modulus G_{LT}=0.5 GPa ; Poisson's ratio ν_{LT} = 0.005 ; the calculation was done up to 2000 Hz. That means about 50 eigenmodes.

We conducted three different virtual experiments of modelling to evaluate the advantages and disadvantages, which criterion being the radiation efficiency of each eigenmode. One can observed that some eigenmodes cannot radiate due to their symmetric shapes. That means that only a few modes can contribute to the efficiency of the radiated sound. So the modal symmetric geometries are counted as negative when they have an even number of bellies and are counted positive when they contain an odd number of bellies ; we also taken into account the magnitude of bellies and their relative areas.

First experiment : the calculation of the eigenmodes of a 2 mm thickness guitar sound board presents 20 radiant modes and 30 modes nonradiant. Lets 20/30

Second experiment, the soundboard is splited longitudinally from the rosette : the calculation of the eigenodes of each half (thickness : 2 mm each one) presents 2x11 radiating modes and 2x14 modes nonradiant. Lets 22/28.

Third experiment : the sound board is still splited, but the left half –basses– has a thickness of 2 mm while the right half –trebbles– has a 3 mm thickness, so that the stiffness is enhenced, and thus eigenmodes distribution is modify . Calculation shows that 25 modes radiate and 25 do not. Lets 25/25.

But moreover, we organized the maxima of the transfer function of radiation of the right part so that it coincide with the minima of the transfer function of radiation of the left part.

TRANSFERT FONCTION BETWEEN SOURCES ON THE BOARD AND FAR FIELD OF THE ACOUSTIC PRESSURE

The radiated air pressure by a vibrating structure of arbitrary shape can be calculated by the Kirchoff-Helmholtz integral. where baffle and using Euler's equation, this integral reduces to the Rayleigh integral, where the pressure in the free space is calculated from the normal speed of displacement of each point of the emitting surface $U_n(r')$:

$$P(r) \approx \frac{j\omega}{2\pi} \int_S \frac{U_n(r')}{R} e^{-jkR} dS$$

with k stands for the wave number, which is coupled to the emitting frequency ω by the dispersion relation. Furthermore, calculating the pressure in the far field allows us to use the Fraunhofer approximation, by only preserving the first and second order of the distance to the observed point

$$R \approx r - \frac{\vec{r}\,'.\vec{r}}{r}$$

so that the integral becomes :

$$P(\vec{r}) \approx \frac{j\omega}{2\pi} \frac{e^{-jkr}}{r} \int_S U_n(\vec{r}\,') e^{-j\vec{k}\vec{r}\,'} dS$$

where

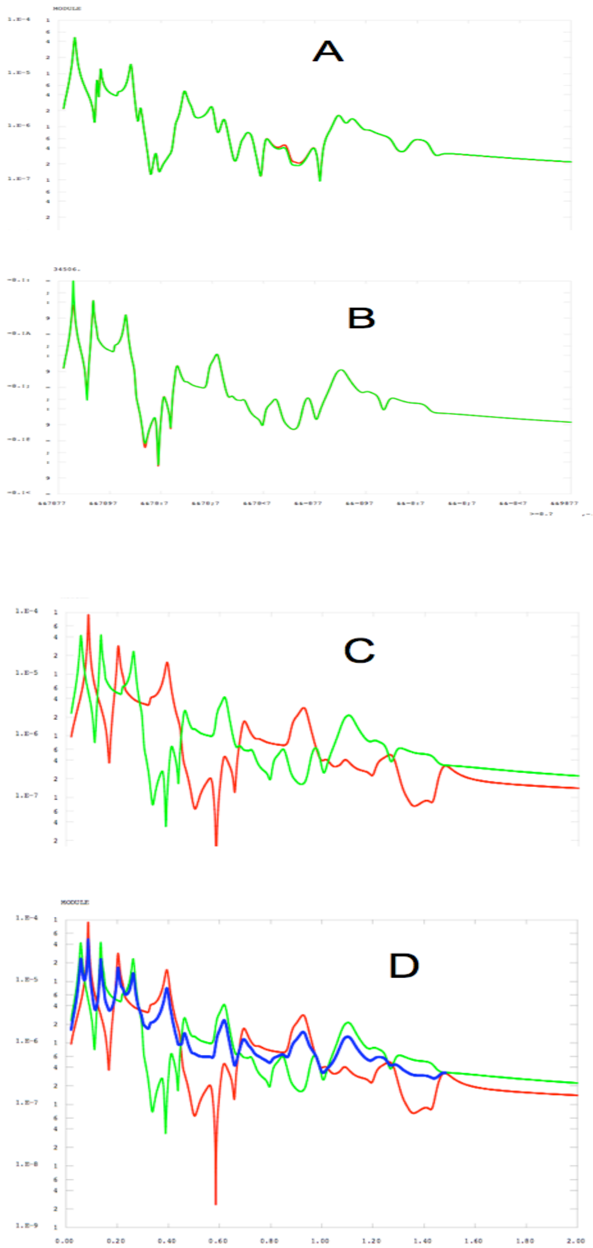
$\vec{k} = k . \frac{\vec{r}}{r}$ is the wave vector.

Considering the pressure in the central point before the plate, the wave vector remains equal for each point on the surface, hence the pressure becomes proportionate to a simple integral on the acceleration profile :

$$P(\vec{r}) \sim \frac{j\omega}{r} \int_S U_n(\vec{r}\,') dS = \frac{1}{r} \int_S A_n(\vec{r}\,') dS$$

As we have calculated the eigenmodes, it is very easy through the finite element code Cast3M to implement this last calculus.

The figures 1 show the results for three different condition studied in terms of generalized transfert fonction. We have plotted the evolution of the module versus frequency with a constant damping of 2%.. One can observe the strong modification of the amplitude for the three models, and the efficient effect of our new proposal.



Figures 1 Transfert Fonction before and after spliting

This figure shows in A the TF of the normal board, ; in B the TF of the splitting board with identical two halfs, notice the rise of the three first pics ; in C we can see the TF of the two separate elements (green/basses and red/trebbles) with inter-digitating pics ; then in D, the blue curve shows the TF resulting from the combinaison of the two elements. Now if we compare D to A we can estimate the enhencement of the radiation of splitting board system. These calculation gives evidences that interditating pics gives a more homogeneous global reponse, what mean the instrument could be better heard.

MEASURING GUITAR RADIATION BEFORE AND AFTER SPLITTING ITS SOUND BOARD

To check the validity of this innovation, we set up an experiment to compare the far field of a single guitar before and after splitting up its soundboard into two distinct components.

Measurement protocol : the instrument is recorded in the same room under guaranteed conditions of reproducibility. Are simultaneously measured : acceleration at two points of the bridge (in front of the 2nd string and 5th string), the sound field in the axis of the instrument at 1 m and 15 m, while the musician plays a chromatic scale. Thus one can obtain the transfer transfer function described in the previous paragraph.

On the other hand, we have used Spectral Density Integration analysis (IDS) [2][3]. IDS is a time-averaged measure method of signal analysis, during a selected window of time (here the duration of a chromatic scale), it measure the percentage of energy in a frequency band compared to the total energy of the signal [ref]. We can thus measure the respective weight (averaged) of spectral components of an acoustic signal for different frequencies bands under a histogram. We use a dB scale as quatitative comparison. This method allows two histograms to be compare.

In our case, we compare the IDS of the far field pressure before and after splitting.

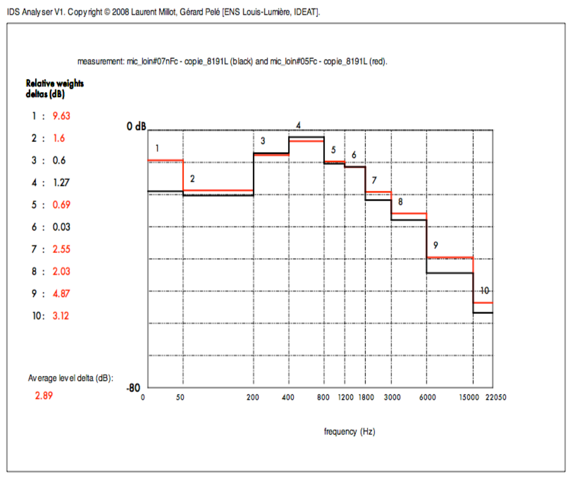


Figure 2 IDS histograms comparing before and after splitting

The black histogramme is the balance of energy for the guitare in its normal configuration, while the red histogramme is the balance of energy for the guitare with its sound board splitted. We can observe that for some frequencies bands the red curve is above the black one, which means that for these band the splitting board has a better radiativity than the normal one, as a result : the splitting board has an average level of 2.89 dB for the whole spectrum taken in account. A more carefull examination shows that the enhencement occurs above 1800 hz, yet we know that human ears are the more sensible between 1800 Hz and 3500 Hz. Then, this could provide a more intellibible and comfortable listening for the audiance.

CONCLUSION

In this préliminary study, calculations and experiments give some results which pull in the same direction. The future will say if this innovation will be catch by the world of manufacturers of musical instruments. For our part we have already verified that the principle worked as well for the guitar as for the violin and even the harp.

REFERENCES

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[3] Laurent Millot : l.millot@ens-louis-lumiere.fr

e-mails

charles.besnainou@upmc.fr

joel.frelat@upmc.fr

Kurijn.Buys@ircam.fr