Voicing and damping in the soundboard of string Instruments

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Abstract
The influence of voicing the string instruments is well known among performers, musicians and violinmakers. Voicing provokes changes in mechanical and acoustical behavior of the sound chest. As a consequence of these changes, the propagation way of mechanical and acoustical propagation in the instrument is different.
In this paper the acoustical parameters related to damping, e.g. the loss factor, have been measured in a cello before and after the voicing of the instrument carried out by the performer, a student of the Faculty of Cultural Musical Heritage Preservation of the University of Bologna. From the measured impulse responses, a slight difference in the propagation of the mechanical wave has been found particularly among the chest, close up to the bridge and to the neck.
As a check of the results, also some measurements of driving-point impedance at the bridge, excited in different points, have been carried out, by using a head-impedance hammer, on the bridge.

Key words: - Voicing, damping, cello, soundboard, vibration, loss factor

INTRODUCTION

This paper investigates the changes in the mechanical behaviour of the soundboard caused by the voicing of the cello. The performer, as well as the violinmaker, "tones" the cello by moving some parts of the instrument, i. e. the bridge and the sound post. They often tone the instrument before a performance, or after a modification of the instrument, as a repairing of the soundboard or the neck.
From a musical point of view, they try to achieve a well-balanced sound from the instrument, in order to get the harmonic distribution of partials among all the notes the best is possible, avoiding unpleasant acoustical phenomenon, as the wolf-note.
From a mechanic and acoustical point of view, they modify the position of the bridge and the sound post in the soundboard. This modification changes the application force coming from the string and going throughout the bridge to the soundboards. The sound post as well, when moved, gives a different coupling between top plate, ribs, back plate and the enclosed air, and the sound chest sounds differently. Being the wood in the chest non-homogeneous, such a modification provokes a different mobility of the soundboard, therefore a modification of damping in the whole body.
Voicing the instruments means to make mechanical adjustments to the whole chest, and in this way to modify the transmission of mechanical waves (longitudinal, torsional and bending) in the Instrument and different sound emission.
The understanding of the vibrational behaviour of the sound chest (mainly motion of enclosed air, A_i, of the sound board, T_i, and of the back plate, B_i,) could be analysed by hologram interferometry, as suggested by many authors [1,2,3]. In this work a different approach has been undertaken, by measuring the difference in damping within the wood, before and after the toning of the instrument, and mapping the loss factor calculated from the measured structural reverberation time.

THEORY

The acoustic propagation of sound of a string Instrument that reaches the ear is mainly coming from the sound chest. The conversion of mechanical energy, coming from an excitation point and going toward a receiving point, into a different form of energy (mainly heat) is called damping. The branch of physics called "structure-borne sound" analyzes the generation and the transmission of the forces and motions in solid bodies.

The damping phenomenon must be analysed starting from the basic equation of elasticity (Hooke law). As suggested by Boltzmann [3], the relation between stress and strain should be related to the "strain history", superposed linear, i.e.:

$$\sigma(t) = D_1 \varepsilon(t) - \int_0^\infty \varepsilon(t - \Delta t) \cdot \varphi(\Delta t) \cdot d(\Delta t) \quad (1)$$

that, with the positions of sinusoidal time-variations and the stress-strain relation written as relaxation function in exponential form, as below:

$$\begin{aligned} \varepsilon &= \tilde{\varepsilon} \cos(\omega t) \cdot \\ \varphi(\Delta t) &= \frac{D_2}{\tau} e^{-\Delta t / \tau} \end{aligned} \quad (2)$$

becomes:

$$\sigma(t) = D_1 \tilde{\varepsilon} \cos(\omega t) - \frac{D_2}{\tau} \tilde{\varepsilon} \int_0^\infty \cos\omega(t - \Delta t) \cdot e^{-\Delta t / \tau} d(\Delta t) \quad (3)$$

Such a complicated equation could be useful only to underline the phase shift between stress and strain. In order to make clearer this relation, it is possible to rewrite the complex modulus of elasticity:

$$D = D' + jD'' = D'(1 + j\eta) \quad (4)$$

and to define the parameter *loss factor*:

$$\eta = \frac{D''}{D'} \quad (5)$$

From an energetic point of view, is possible to obtain a different relation for the loss factor. Considering the system oscillating at a circular frequency f by means of a shaker, the energy density increases, while the mechanical energy (related to the displacements of the body) remain constant. The energy provided in the following time by the shaker is dissipated into heat. The loss factor can be described as the ratio between the quantity of energy that is lost and the whole reversible mechanical energy:

$$\eta = \frac{E_l}{2\pi E_R} \quad (6)$$

Considering the energy converted into heat in the time t:

$$E_l(t) = \int_0^t \left(E_{R0}(t) - E_l(t)\right) \eta \omega \, dt \quad (7)$$

and differentiating eq. (7) with respect to time, it is possible to obtain:

$$\begin{aligned} & E_l(t) = E_{R0}\left(1 - e^{-\eta \omega t}\right) \\ \Rightarrow \quad & E_{RT_{60}} = E_{R0} e^{-\eta \omega T_{60}} \end{aligned} \quad (8)$$

that leads to the relation:

$$\eta = \frac{\ln(10^6)}{2\pi f \cdot T_{60}} \quad (9)$$

With reference to this formulation, in this paper the experimental measurements have been carried out by getting the *structural reverberation time* in 19 points of the soundboard, and calculating the corresponding loss factor in one-third-octave band.

MEASUREMENTS

Two different kinds of measurements have been conducted.

In a first step, the mobility function in different position on the bridge has been measured. The measurements have been repeated for the different position of the strings, in order to obtain the mechanical impedance, as requested for virtual reconstruction of string instruments, as shown in [5], and already programmed in further analysis. The output signal has been connected to a FFT analyser (namely, OnoSokky CF 5200), processed in real time and stored.

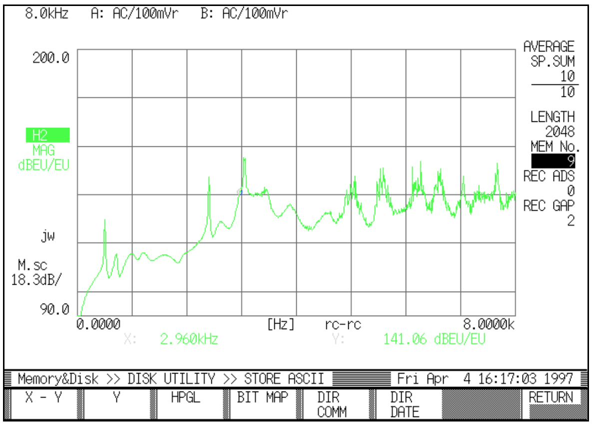

Figure 1 Driving point mobility function measured on the bridge

In a second step, the loss factor of the soundboard has been calculated. A hammer with head-impedance transducer has been utilized (B&K 8202 and B&K 8001). The output signal coming from the force transducer and the accelerometer (B&K 4374) has been conducted to the FFT analyser and a DAT (Aiwa St-1). The waveforms have been successively transferred in the laboratory from DAT to a PC and then analysed by using a wave editor with homemade extension and specialised software (Adobe Audition and Aurora). The calculus of the structural reverberation time has been processed in real time, from the FFT analyser, and then compared with the ones calculated later, in laboratory. The loss factor has been calculated in a following step, from the second elaboration.
Among all the measurements, 5 different impulses have been considered for each measuring point, and than the results have been averaged.
The measuring points considered on the soundboard, covered the entire surface. They have been taken all around the ribs, at 6 cm from the external perimeter, while 4 measuring points have been chosen on the longitudinal symmetry line.

RESULTS

From a musical point of view, voicing the cello means the sound become more "open", coloured, vivid, balanced; his "metallic" components become limited. Voicing the instruments, from a practical point of view, means moving the components of the instruments (e.g. the bridge and the sound post) until the performer feels a good response from the sound chest.

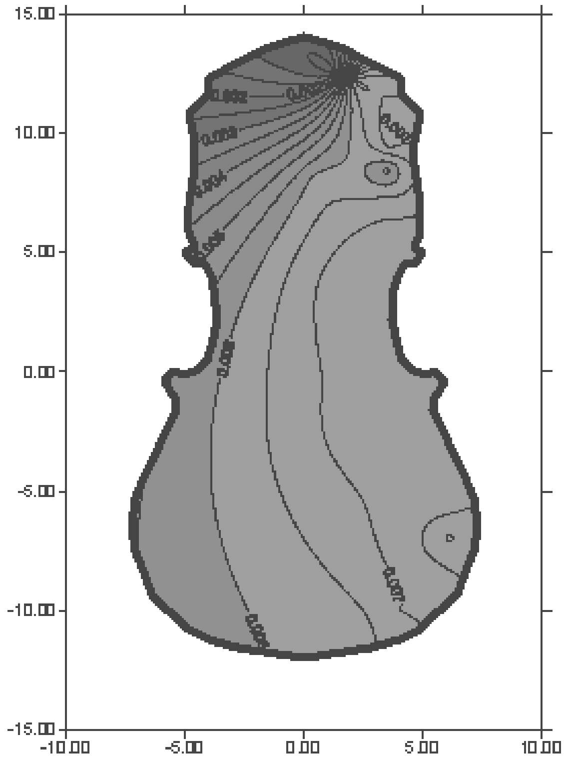

Figure 2 Loss factor at 500 Hz before voicing

From a mechanical point of view, voicing the cello means to modify the position of the bridge on the soundboard, and to change the application force coming from the string and going, throughout the bridge, to the sound chest. Being the wood non homogeneous, and particularly being the wooden vein oriented, the damping characteristics are quite different each others, considering different paths of propagation. In such a way, modifying the position of the bridge, the driving point of excitation of external bowing force changes, and in such a way also the radiation on the sound board changes, being the wooden veins oriented and the sound board non homogeneous.
From the mapping of the loss factor it is possible to observe that the voicing gives a slight modification of the damping characteristics of the soundboard, which becomes more relevant at higher frequencies. Probably, the psycho-acoustic sensation of "colour" is related to higher partials of the sound emission of the sound chest, as well as

the sensation of "open sound" seems related to a wider range of frequency included in the sound propagation of the body of the instrument.

It is still quite difficult to deeply understand in which way these differences of damping characteristics of the sound chest (in this case the sound board of the cello) are related to acoustic quality of the sound generated by the instrument. While from a purely mechanical point of view it is no difficult to foresee that such modifications provoke different propagation of mechanical waves throughout the sound chest, due to the different damping characteristics of the body of the instrument, from the analysis of the mapping parameters is not so easy to interpreter the changes of damping of the wood, by conventional ways.

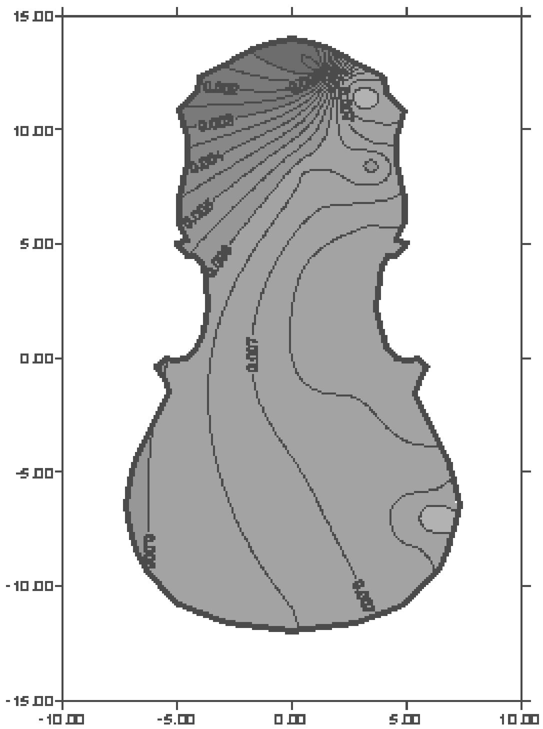

Figure 2 Loss factor at 500 Hz after voicing

CONCLUSIONS

Voicing the soundboard of the cello causes different damping components in the sound chest. These differences have been measured in one cello by means of a head-impedance hammer in the bridge and an accelerometer in the soundboard. From the analysis, voicing resulted to influence especially high frequencies, where the chest sounds more evidently. Voicing the cello acts at frequencies higher than 2 kHz, which are related with a sensation of coloured sound, rather than a specific frequency.

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