

# On the toning of cello: the effect on damping in the sound board

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**Abstract:** The influence of toning the string instruments is well known among performers, musicians and violin makers. Toning 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 toning 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.

## INTRODUCTION

This paper gives a contribution on the definition of the changes in the mechanical behavior of the sound board caused by the toning of the cello. The performer, as well as the violin-maker, “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 sound board 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 an mechano-acoustical point of view, they modify the position of the bridge and the sound post in the sound board. This modification changes the application force coming from the string and going throughout the bridge to the sound boards. The sound post as well, when moved, give 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 sound board, therefore a modification of damping in the whole body.

Toning the instruments means to make mechanical adjustments to the hole 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 behavior 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 analyzed 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. From the measurements, also some examples of impulse responses measurements have been conducted

## THEORY

Considering the sound of a string Instrument that reaches the ear, mainly of the acoustic propagation is coming from the sound chest. The generation and the transmission of the forces and motions in solid bodies are analyzed by the branch of physics called “structure-borne sound”. 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 damping phenomenon must be analyzed 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 defining the parameter *loss factor*:

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

From an energetic point of view, is possible to obtain an other 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  $t$ :

$$E_i(t) = \int_0^t (E_{R0}(t) - E_i(t)) \eta \omega dt \quad (7)$$

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

$$E_i(t) = E_{R0} (1 - e^{-\eta \omega t}) \quad \Rightarrow \quad E_{RT60} = E_{R0} e^{-\eta \omega T_{60}} \quad (8)$$

that leads to the relation:

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

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

### EXPERIMENTAL MEASURES

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 analyzer (namely, OnoSokky CF 5200), processed in real time and stored.

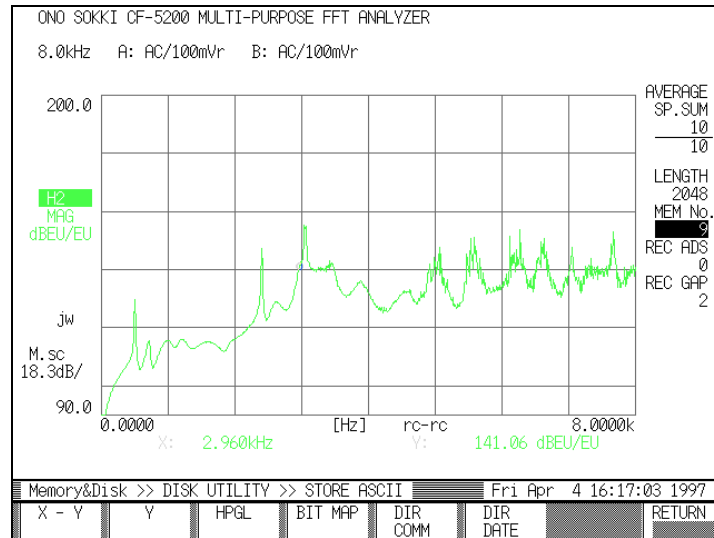


FIGURE 1 Driving point mobility function measured on the bridge

In a second step, the loss factor of the sound board has been calculated. An hammer with head-impedance transducer has been utilized (B&K 8202 and B&K 8001). The output signal coming from the force

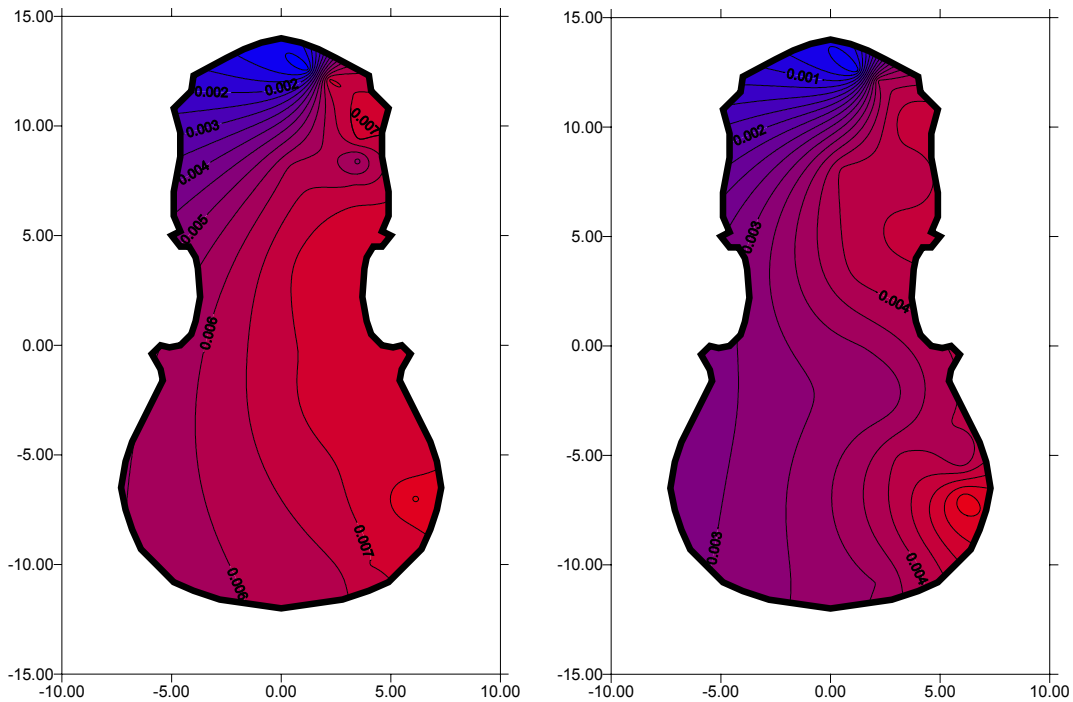
transducer and the accelerometer (B&K 4374) has been conducted to the FFT analyzer and a DAT (Aiwa St-1). The waveforms have been successively transferred in the laboratory from DAT to a PC and then analyzed by using a wave editor with homemade extension (COOLEEDIT 96 and AURORA) and a specialized software (MELISSA 10D). The calculus of the structural reverberation time has been processed in real time, from the FFT analyzer, 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 sound board, covered all the 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, toning the cello means the sound become more “open”, colored, vivid, balanced; his “metallic” components become limited. Toning 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.



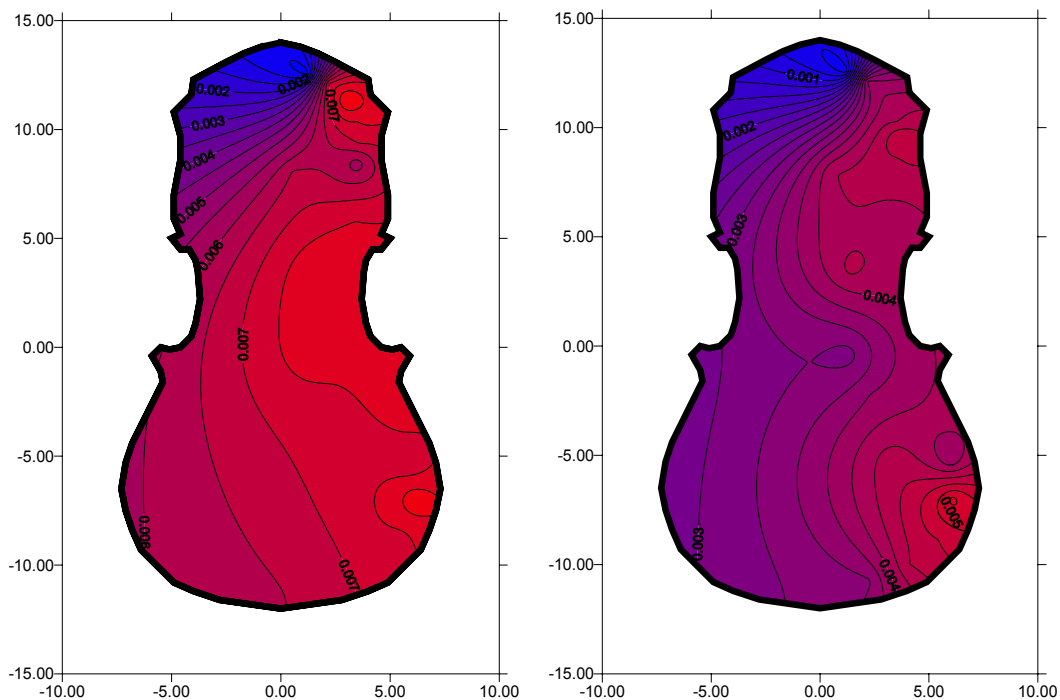
**FIGURE 2** Loss factor at 500 (right) and at 1000 Hz (left) before the toning

From a mechanical point of view, toning the cello means to modify the position of the bridge on the sound-board, 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 toning gives a slight modification of the damping characteristics of the sound board, that becomes more relevant at higher frequencies. Probably, the psycho-acoustic sensation of “color” 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 interpret the changes of damping of the wood, by conventional ways. Probably, the best way to underline the influence on sound quality of the instrument, is a virtual reconstruction of the sound quality of the hole sound chest, as already proposed [5].



**FIGURE 3** Loss factor at 500 (right) and at 1000 Hz (left) after the toning

## CONCLUSIONS

The measurements of the damping component of the sound board of a cello have been undertaken in order to investigate the mechanical propagation of waves on the sound board. The measurements have been conducted with two different toning configuration of the sound board, the first one with the instrument not toned, and the second one with the instrument toned, and measuring the third-octave band loss factor of the sound board, by using a head-impedance hammer on the bridge and a accelerometer in

the body. From the analysis, a slight influence of toning on the damping characteristics of the sound board have been found especially at the higher frequencies, where the chest sounds more evidently. The data will be also utilized for further analysis and for virtual reconstruction of the sound of the cello, following what already proposed in recent researches.

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