

# Using of pulse interferometry on musical instruments

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From the viewpoint of musical acoustics, sound is defined as a vibrating movement of material recognized by our sense of hearing. Musical acoustics concerns on generation, transfer and perception of the musical signal, which is, in its natural form, generated by the mechanical system of a classic musical instrument. Therefore the analysis of the vibrating movement of the musical instrument and its individual parts is an essential component of research of musical instruments. Our university “Academy of Performing Arts” (AMU) has three faculties; music, film and television, and theatre. The Sound Studio is located at the Faculty of Music in the center of Prague directly under Prague Castle and it has been involved in musical acoustics research for 35 years.

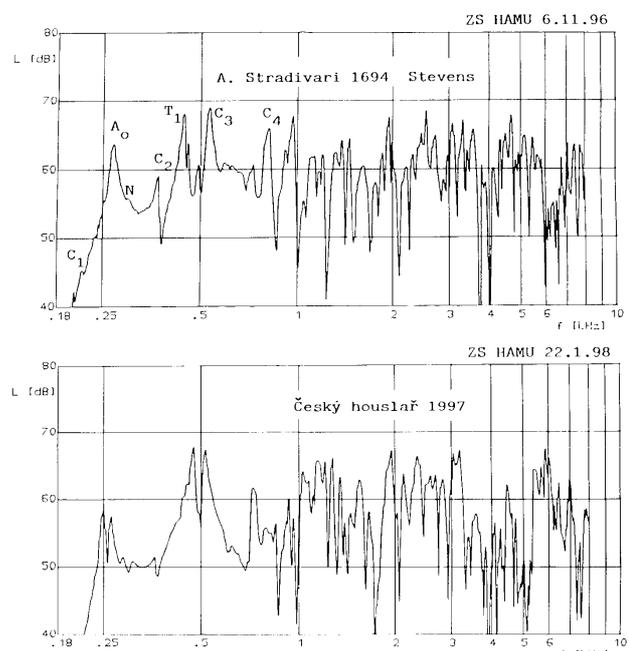
The Sound Studio has two departments. The first one, sound engineering department, where do the future sound masters study, has a dedicated recording studio. This studio is perfectly equipped with control rooms, an electronic sound studio and other operational rooms. In the second one, department of musical acoustics, there is performed a research that is financially supported by national and international grant projects. The department of musical acoustics is equipped with a non-reflection room, the third largest in our country, and further special rooms for psychoacoustic testing and a small laboratory for physical acoustics with a two laser-beams vibrometer Polytec and interferometer Q-600. We purchased the latter from the company Dantec Dynamics GmbH this past May.

Our research is oriented mainly towards the problematic of timbre and sound quality of classic musical instruments, and along physical-acoustic and psychoacoustic lines. Searching for physical causation of the quality of musical instruments has been since the Chladni times related to the monitoring of node lines and determining frequencies which corresponds to resonance modes for plates, mainly on bow instruments,. Violin makers are still using this simple method.

A very widely used visualization method in musical instruments research was stroboscopy. This method was used for studying the oscillation of player’s lips on brass wind instruments or clarinet reeds. To analyze the vibration of strings at bow instruments, it is also possible to use videokymography, better known as a diagnostic method of vibrating the vocal cords. This basically concerns a single-line recording by a high-speed video camera.

The use of holographic interferometers was a fundamental advantage for studying vibrations of the widest range of musical instruments. The first interferogram of the violin was already published back in the 1960s. Aside from visualization and analysis of vibrations of individual resonance boards comprised of resonance boxes, holographic interferometry also enabled the visualization of vibrations of air jets, reeds and resonance columns, mainly in organ pipes. In 1969, Ising analyzed the movements of reeds in flue organ pipes.

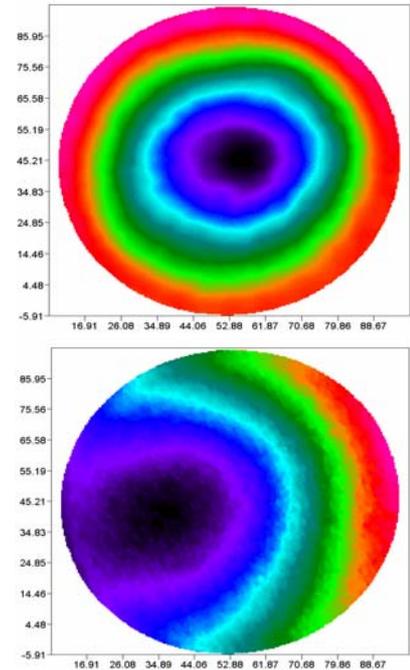
A common disadvantage of these historic imaging methods was the great difficulty in quantifying the results of measurement. But this is essential during research where the results are determined by specific use in the manufacture of musical instruments, which happens to be our case. The selection of a pulse interferometer Q-600 was influenced (among other things) by experience with a simple scanning vibrometer, which we comprised from a two beams vibrometer from the company Polytec and from 3D linear motion slides run by a computer system. However, we do not use this simple piece of equipment to make the vibrations of violins, guitars or other instruments visible, but rather for discovering the frequencies of individual modes of their relatively difficult resonance characteristics.



**Fig.1** The example of resonance characteristics of the Stradivarius violin and the Czech contemporary instrument

We are learning to handle the interferometer Q-600 on the first measurements of musical instruments; we are testing various methods of driving vibrations of the measured object and the influence of outside conditions on the results of measurement. The most simply shaped vibrations between musical instruments can be found in homogenous membranes, percussion instruments, such as on a small drum or tambourine. Upon acoustic driving by a plane wave, it is possible to build the basic circular resonance mode and to monitor, for example, non-uniform stress of the membrane or the influence of dampening of the membrane with the hand.

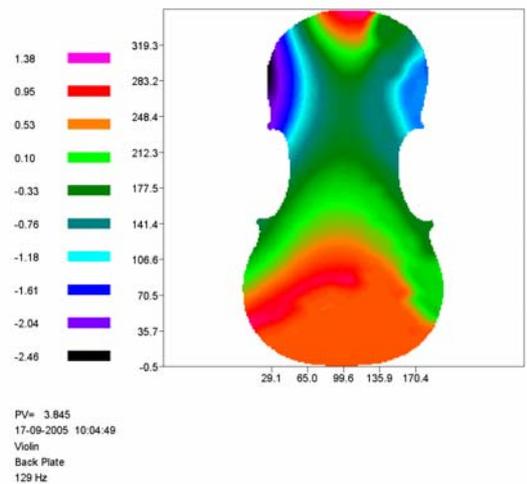
For driving higher modes – circular and radial modes – it is necessary to use the directed acoustic driving corresponding to the locations on the membrane, because the plane wave drives and dampens higher modes at the same time. We have not yet realized this driving.



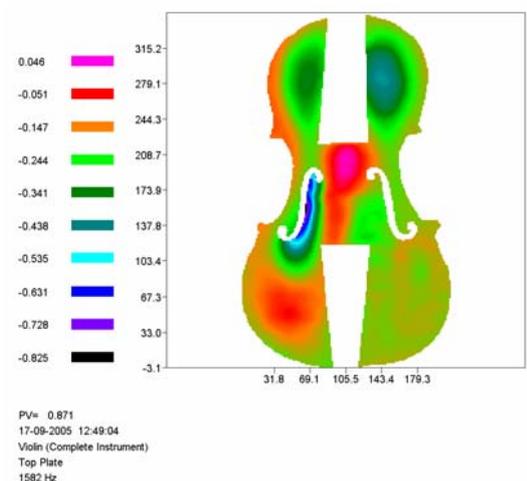
**Fig. 2** The non-uniform stress of the membrane and the dampening of the membrane with the hand

Another example is the basic mode of acoustically driven violin back -plate. If the driving frequency is not exactly in the resonance with the mode of the plate, the form of the mode is understandably deformed. Wood, as opposed to a membrane made from artificial materials, is not homogenous and the thickness of the plate is also changing. Searching for the optimum shape of the plate, if possible with the least amount of dependence on the qualities of the wood and paint, is not only in the establishment of resonance frequencies of the plate, but also in the behavior of the plate in the immediate location of resonance.

**Fig. 3** 1<sup>st</sup> resonance mode of the back violin plate

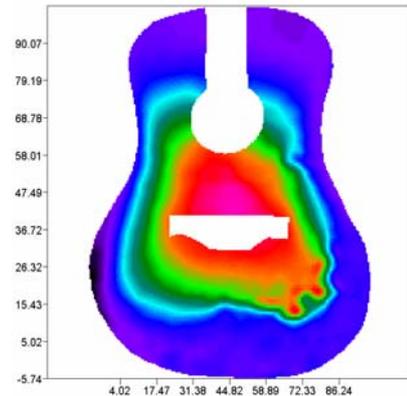


Vibrations of the configured box of finished violins are of course more complex than vibrations of individual parts. From the classic interferometers, the basic shapes of vibrations of the entire box are known. The top plate vibrates asymmetrically, because underneath it is located a bass bar (on the left) and a sound post (on the right). Our aim is to make concurrently visible, with the help of mirrors, the vibrations of the back plate, the top plate and the ribs. Nobody has done this yet. We are also interested in the simulation of the oldest methods to search the resonance qualities of plates for entire instruments. The violin maker simply knocked on the plate or box with his finger and by listening found the resonance frequency or pitch. Therefore we are planning to realize the strict impulse drive of vibrations and determine the correlations between measured and subjectively perceived values.



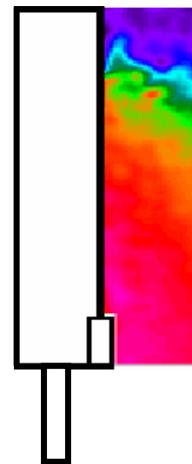
**Fig. 4** *The violin box resonance at the frequency 1582 Hz*

Another example concerns identification of a problem in the top plate of a guitar. Upon changing the frequency of the basic resonance mode, influence of a flaw in manufacturing showed up, more specifically the influence of a non-homogenous plate in the designated location. Under 195 Hz and above 205 Hz, the plate does not vibrate.



**Fig. 5** *Identification of some problem in the top plate of a guitar*

The last example is the attempt at visualization of the movement of air in front of the mouth of organ pipes. For driving the tone, instead of air, carbon dioxide was used, because of the difference in density of the gas. By this convincing method, it is possible to exactly demarcate air whirlpools, and therefore also the movement of the air reed. The results however were not yet satisfactory, and there are recorded a series of methodical errors, beginning with the choice of a trigger signal, the method of triggering, etc. The image displays the individual phase of expanding pressure wave in front of the mouth of the pipes when triggering a sinus signal by a frequency just like a tone emitted from the pipe. We have not been able to make visible the capture of the reeds movement .



**Fig. 6** *Air movement in front of the organ pipe mouth*

What all can we still solve to get the full use out of the system Q-600? Firstly, we can resolve all methods of acoustic and mechanical driving and those highest resonance modes. Relating to this, there is also the question of fixing the work or entire musical instrument during the act of measuring. There is also the problem of synchronization by continual or transient acoustic signal, all of this with a respect to the required repeatability and validity of the results of measurement. We want to identify hidden flaws, such as cracks in the plates of bow instruments, comparing the condition of these instruments before and after the impact of the violin maker. This means researching the transient happening upon impulsive driving of the measured object. Other possible task is the joining of distinct documentation of rare historical instruments in museum collections. We would also like to study vibrations of air columns for wind instruments and the desirable or undesirable co-vibration of the walls of these instruments. We are planning to expand 1D measurement of musical instruments to 3D measurement, and search for the relation of these measurement results to the quality of sound of the measured instruments. The presented results of measurements are the first look into the untold possibilities of pulse interferometry. Visualization and analysis of vibration is not only an effective means for musical instruments research, their construction, manufacturing technology and their sound qualities, but also a very modern means of learning not only in musical instruments acoustics. We therefore have before us vast possibilities and perspectives.

## Acknowledgment

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## 12<sup>th</sup> International User Meeting and Conference

Dantec Dynamics GmbH, Ulm, Germany  
October 12 –13, 2005