Microphone Array Measurements of the Grand Piano

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Abstract

In an on-going project a series of measurements is taken on four concert grand pianos in seven different stages of production. A noninvasive microphone array method is utilized, impulse responses are obtained through the SineSweep technique, the measured sound pressure is back-propagated to the radiating soundboard surface using a minimum energy method. First results are presented.

Introduction

The majority of the sound energy radiated by a grand piano originates from the soundboard, which amplifies the vibrations of the strings via the bridge. Due to the large size of the soundboard as well as its irregular shape, measuring deflection shapes is a nontrivial task. Paul Bilhuber was one of the first to systematically describe the impact of slight design variations to the vibrational behavior of a piano soundboard [1]. Common ways of exciting the Soundboard are loudspeakers [2], impact hammers [3] and acoustic shakers [4]. Traditionally vibrational responses are measured with piezoelectric transducers which are glued to the soundboard [5]. A laser speckle pattern interferometry method is used by Moore to visualize deflection shapes up to 3 kHz, experimentally confirming a transition frequency of approx. 1 kHz, from which on the soundboard motion is governed by the ribs [6]. Chaigne uses a scanning laser vibrometer to measure the transverse velocity of an upright piano soundboard, showing the influence of irregular rib spacing on the higher frequency operating deflection shapes [7]. Piezoelectric accelerometers can affect the acoustic vibrations of the soundboard due to the added mass. Optics based methods have other disadvantages such as the need of averaging over longer time spans, thus without great effort being able only to measure stationary behavior. To this end, a noninvasive microphone array method is utilized for the present work. A series of measurements is taken on four concert grand pianos in seven different stages of production, starting with the glue-laminated soundboard planks and ending with the completely assembled piano in concert tuned state. Comparable measurements of an unmounted grand piano soundboard are published by Berthaut [8]; therein measurements on the vibrational characteristics of a baby grand soundboard with free boundary conditions are presented.

Experimental Arrangement

Figure 1 shows the experimental configuration: The array consists of 105 microphones successively placed in 18 positions parallel to the piano soundboard, resulting in a total number of 1890 recordings (48 kHz, 24 bit) of which 1289 microphones cover the actual surface. A distance of 40 mm between each microphone yields a theoretical spatial resolution of up to approx. 4 kHz. The Soundboard is excited using an acoustic vibrator (Bruel & Kjaer model 4809) at 15 positions associated with string termination points on the bass and main bridge. Sensors at the driving points measure the input force (PCB 208C01) and the resulting acceleration (PCB 352C23) for input mobility calculations. For the excitation an exponential sine sweep is used:

$$f(t) = \sin\left[\frac{T\omega_1}{\ln(\frac{\omega_2}{\omega_1})}\left(\exp^{\frac{t}{T}\ln(\frac{\omega_1}{\omega_2})} - 1\right)\right] \quad (1)$$

with $\omega_1 = 2\pi * 1$ (rad/s), $\omega_2 = 2\pi * 24000$ (rad/s) and $T = 24$ (s).

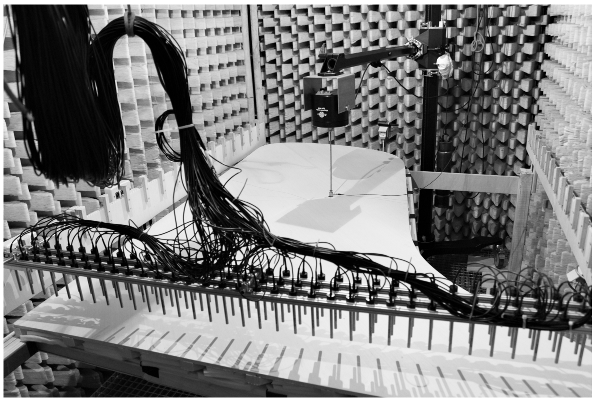


Figure 1: Experimental arrangement

Analysis

To obtain impulse response functions the so called *Sine sweep technique* is utilized [9]. The method - originally proposed for impulse response measurements in room acoustics - is successfully utilized for piano soundboard measurements by Ege [10].

The deconvolution process is realized by a linear convolution of the measured output $y(t)$ with the temporal reverse of the excitation sweep signal $f(t)$ (1):

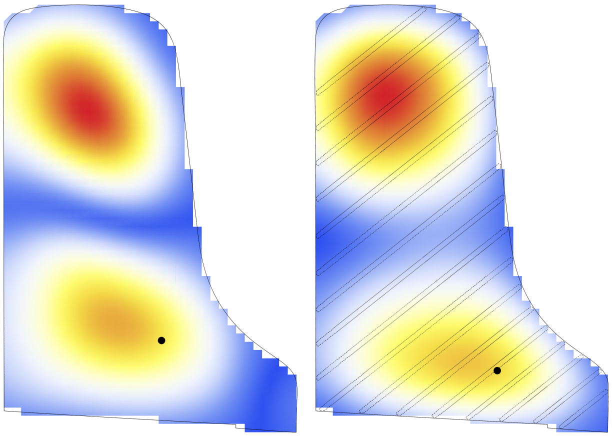
$$h(t) = y(t) \otimes f^{-1}(t) \quad (2)$$

If T is large enough the linear part of an impulse response of a weakly non-linear system is temporally separated from several non-linear parts, representing the harmonic distortion of various orders. As a consequence it is possible not only to calculate the linear impulse response of a mildly non-linear system but also to gain information about the systems level of non-linearity.

The measured sound pressure is back-propagated to the radiating soundboard surface using the minimum energy method proposed by Bader [11, 12].

Results

Figure 2 shows operating deflection shapes of the soundboard driven at resonance peaks (a) 24 Hz and (b) 25 Hz in two different stages of production. Gluing the ribs to the back of the soundboard increases the stiffness and thus increases the resonance peak frequencies.

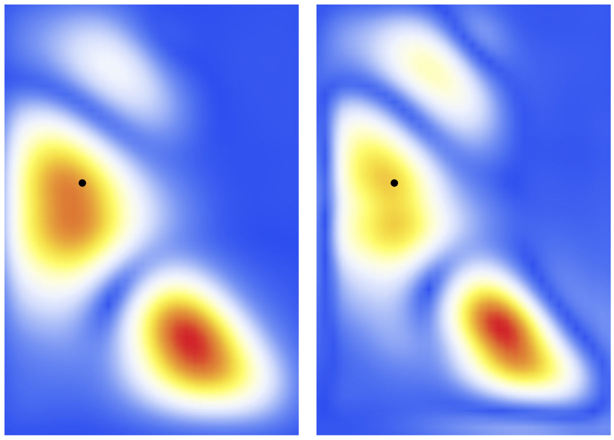


(a) (b)

Figure 2: Operating deflection shapes at (a) 24 Hz in production stage 1 and (b) 25 Hz in production stage 2. Application of the ribs raises the resonance peak frequencies due to increased stiffness.

Figure 3 shows an exemplary result of propagating the recorded sound pressure back to the soundboard surface. The reconstruction even shows the boundary of the soundboard where no radiation can take place and which is not visible in the measurement data.

The empirical findings will contribute to the formulation of a real-time physical model to help piano makers estimate the impact of design changes on the generated sound.



(a) (b)

Figure 3: Advantage of the back propagation method. (a) shows the recorded radiation (all 1890 microphones) at 41 Hz. The microphones have a distance to the soundboard of Δz=40 mm. (b) the recorded sound pressure is back-propagated to the surface with α=1. The black dot indicates the driving point position.

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