Sound Radiation from a Grand Piano

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Abstract

Besides tonal partials the sound radiated from a grand piano contains noise components arising from the excitation of the normal modes of the sound board. The radiation characteristics in the different frequency regions will be shown by measured sound spectra, sound field analysis and recorded tone samples. For the low components up to 200 Hz, the figure-eight-shaped radiation of the soundboard is determined by its vibrational dipole character.

Soundboard vibration

The transformation of the strings' vibrational energy into sound is governed by the properties of the sound board. To describe its vibrational behaviour at selected frequencies modal analysis is a common measurement tool which among others can show the deflection of its surface as animated pictures on a computer screen. Most important for the vibration characteristics are the resonances or *modes* which are determined by the soundboard's size, shape and structure, i.e. density and elasticity of the wood used. The reaction of the sound board on a complex excitation spectrum like that of a vibrating string depends on the relative position of the partials and the modal frequencies of the soundboard. Particularly in the low frequency range up to 500 Hz sound radiation is closely related to the mode shapes of the soundboard's resonances.

Fig.1 shows the lowest resonance of a grand piano soundboard in form of the two extreme deflections displayed with oversized amplitudes. Each point on the grid of the soundboard corresponds to a measurement of magnitude and phase of a vibrational quantity e.g. acceleration, velocity or deflection. It is to be seen that the soundboard acts like a piston moving up and down with all its parts in phase acting as a dipole source. This modal shape is valid not only at its modal frequency but also in the frequency range below. Above the first resonance, the shape is more and more mixed with that of its second mode, a mode where the surface of the soundboard is separated into two parts of opposite phase by one nodal line (Fig.2).

To visualise the sound field generated in the frequency range of the first soundboard mode the modal analysis equipment was used to measure and display the sound pressure amplitudes and phases for selected frequencies as described in a former paper [1]. Fig.3 shows the sound field in two planes of equal distance (30 cm) on both sides of the sound board for a frequency near the first mode. The scalar quantity sound pressure is displayed like a vector in the vertical direction showing (of course more clearly in an animated form) the opposite phase on the two sides of the soundboard. In the same way a vertical plane in front of the instrument has been measured, the result in Fig.4 is shown for a frequency of 100 Hz for the two extreme values of sound pressure. The dipole character with low radiation in the soundboard plane is confirmed again.

Spectrum of a piano tone

The spectrum of a played piano note contains not only the nearly harmonic partials but also noise components arising from the excitation of the modes of the sound board. This becomes clear when a high note (c''' = C_6, 1046 Hz) is analysed as in Fig.5 in two different microphone positions, above and in front of the grand piano. Below the frequency of the fundamental particularly above the soundboard two different components are to be seen: one slowly decaying 90 Hz tone and a broadband attack noise of about 70 ms duration generated by the impulsive excitation of the resonances of the soundboard and the frame.

The 90 Hz tone was found to be a resonance of the iron frame with a much higher Q-factor than the resonances of the wooden soundboard. Though it is not radiated directly, its vibrations are transferred to the soundboard and - due to its low frequency - amplified and radiated by the first soundboard mode with its dipole character. This is the reason why this component is cancelled in the soundboard plane in front of the instrument (Fig.5 lower graph).

Radiation of the spectral components

The radiation characteristics of three spectral components of high piano notes, 90 Hz tone, attack noise and fundamental has been investigated by multichannel recordings in a semianechoic chamber, all microphones at 3 m distance from the centre of the soundboard. The results are displayed for four different notes (c',c'',c''',c'''' = C_4 - C_7) in Fig. 6 in the vertical plane of principal radiation. Generally the dipole character of the 90 Hz tone appears as a the upper half of a figure-eight shape, since the lowest microphone was located in the plane of the soundboard. A clear difference is to be seen between the two sides of the grand piano: the level minimum in the soundboard plane is more clear on the open side, while on the other side the lid inhibits the sound pressure cancellation.

The attack noise shows no preferred direction and no effective shielding by the lid. The differences for the four played notes refer to the different points of excitation of the soundboard resonances by the pressed key. The tonal components show the well known directivity with interferential fluctuations [2]. It is remarkable that the level difference of the 90 Hz component and the fundamental is only 7 dB above the instrument and 45 dB in the soundboard plane in front of the instrument. This difference is clearly audible, when the sound signals of the corresponding microphones are compared. The lack of the low 90 Hz tone results in an unnatural sound comparable with those piano sounds produced by the early synthesizers confirming the results of Chaigne and Askenfelt who found it necessary to add the attack noise to synthesized piano sounds [3].

The radiation in two more planes, the other vertical one and the horizontal plane is shown in Fig.7. It confirms the previous results particularly in the region in front of the instrument where the lid cannot act as separating element for the sound of opposite sign produced on both sides of the soundboard.

Conclusion

The sound radiation at low frequencies is determined by the vibrations of the soundboard. The dipole directivity of the 90 Hz component applies to all partials in the frequency range of the first resonance, which depends on the size of the soundboard. The lack of this frequency range in the plane of the soundboard evokes a poor sound impression with synthetic character, that's why listening and microphone positions in this plane should be avoided. The short attack noise excited with each played note shows no preferred direction of radiation. If in a concert hall a wall reflection of a significant attack noise arrives delayed, it may be interpreted as a spatially isolated sound source since the direct noise component is masked by the varying tonal components. This may become disturbing at distinct areas of the concert hall because its character is constant for each note played in musical phrases.

References

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[2] Meyer, Jürgen: Die Richtcharakteristik des Flügels, Das Musikinstrument 14 (1965), p.1085-1090,

[3] Chaigne, A., Askenfelt, A.: Numerical simulations of piano strings. Speech Trans. Lab.Quart.Progr. and Status report, Royal Institute of Technology, Stockhom STL-QPSR 4/92, p.51-72

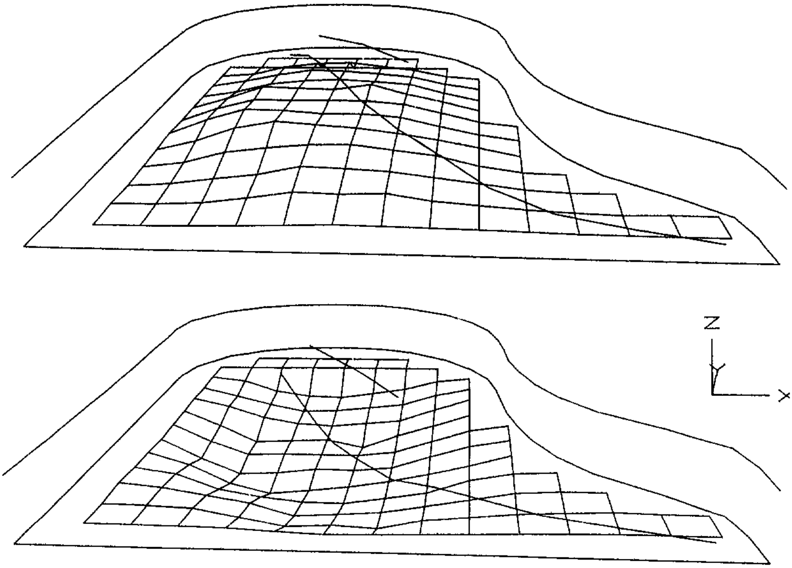

Fig.1. First vibrational mode of a grand piano soundboard at 107 Hz

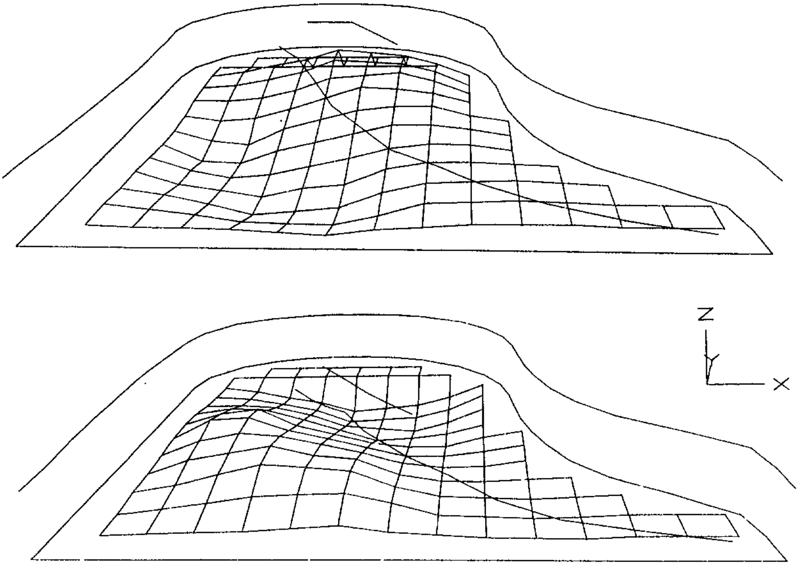

Fig.2. Second vibrational mode of a grand piano soundboard at 173 Hz

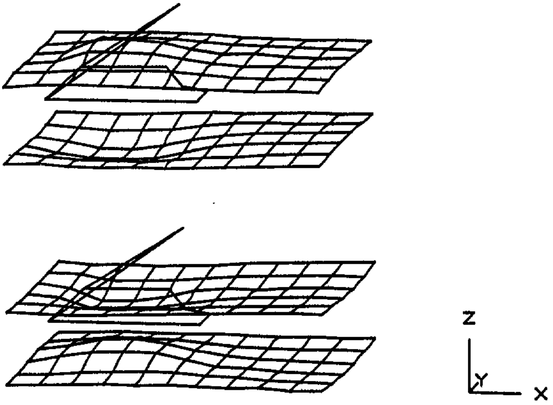

Fig.3 Sound field in two planes on both sides of the soundboard at 100 Hz, sound pressure is proportional to the vertical deflection

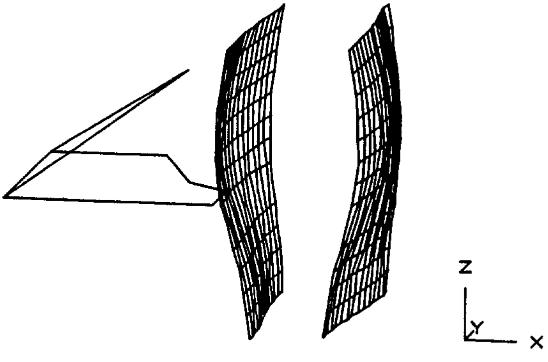

Fig.4 Sound field in front of the grand piano at 100 Hz, sound pressure is proportional to the horizontal deflection

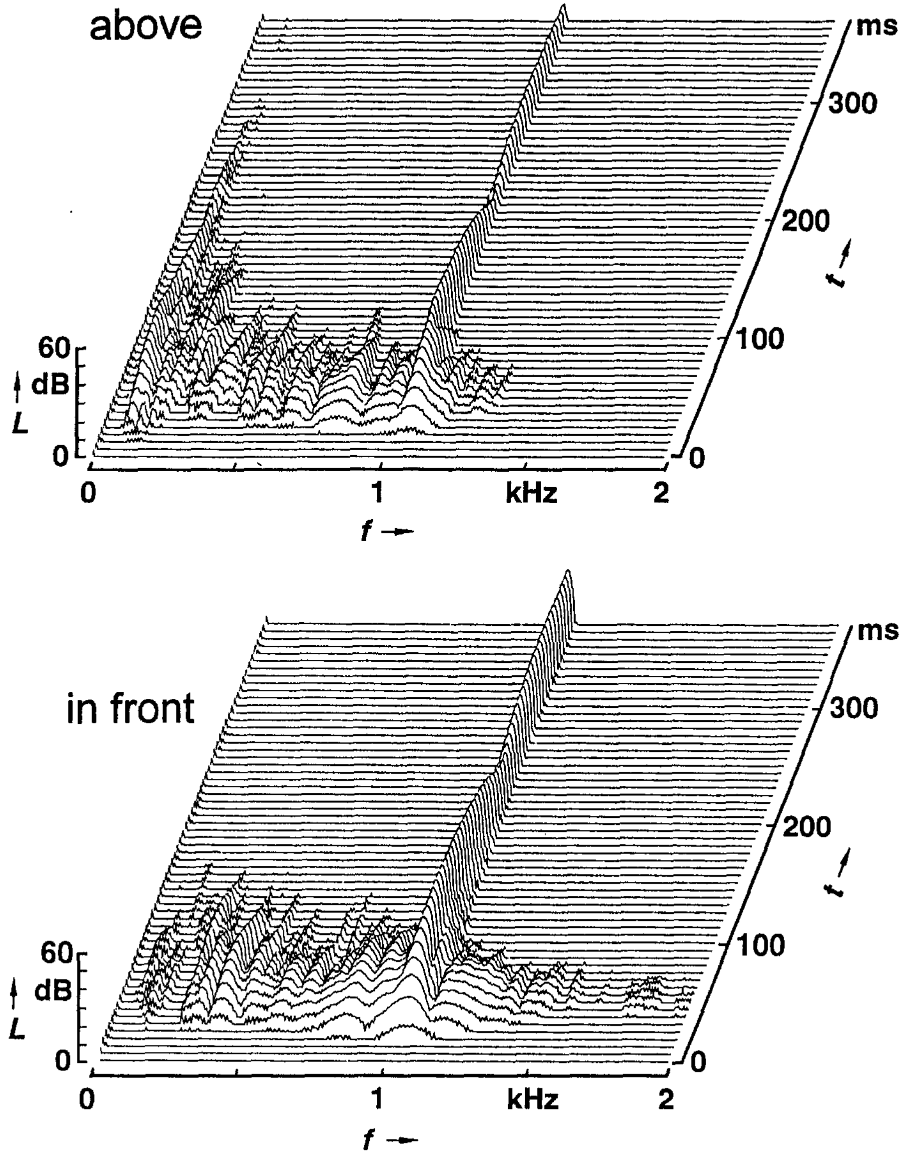

Fig.5. Sound spectrum of the note C6 (1046 Hz) above and in front of a grand piano with open lid, distance 3 m from soundboard centre

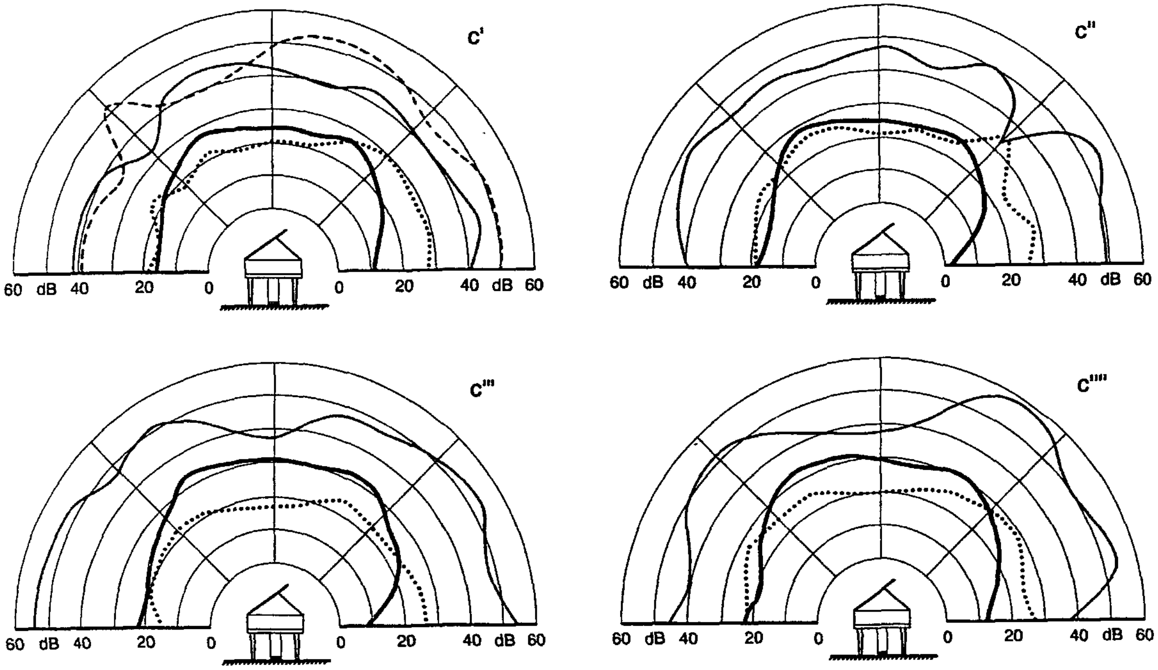

Fig.6 Radiation of spectral components in the vertical plane of principal radiation, indicated levels are relative
thick line: 90 Hz tone, dotted line: attack noise, thin line: fundamental, dashed line: 2nd partial

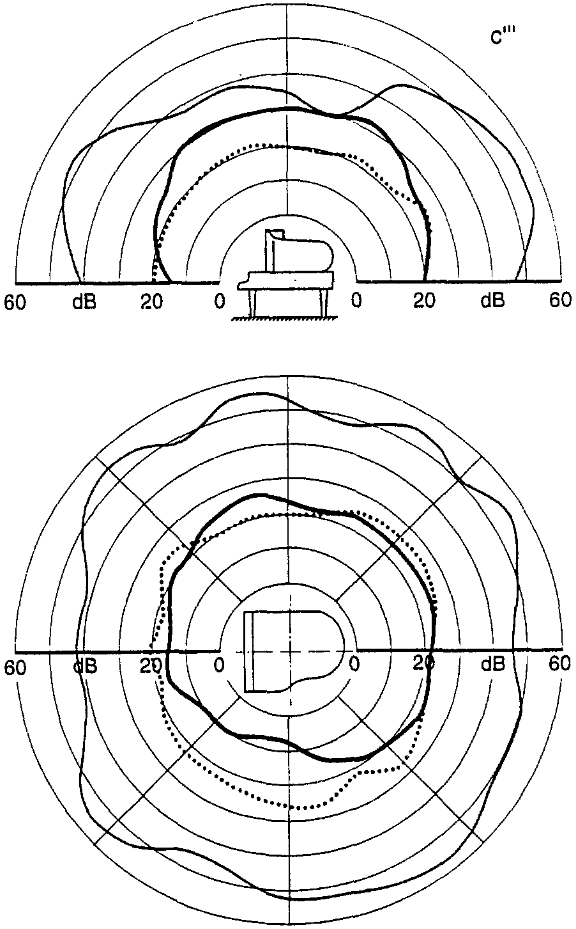

Fig.7. Radiation in the other vertical plane (pianist's plane, above) and in the horizontal plane (soundboard plane, below)