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Chapter 2 : Structural acoustics - Wikipedia

Sound is produced by vibrations and as such can be dampened or augmented based on materials selection. This title looks at the effects of sound and vibration on thin structures and details how damage may be avoided, acoustical effects created, and sound levels controlled.

This is an open access article distributed under the Creative Commons Attribution License , which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Abstract Research has shown that the soundboard plays an increasingly important role compared to the sound hole, back plate, and the bridge at high frequencies. The frequency spectrum of investigation can be extended to 5 kHz. Design of bracings and their placements on the soundboard increase its structural stiffness as well as redistributing its deflection to nonbraced regions and affecting its loudness as well as its response at low and high frequencies. This paper attempts to present a review of the current state of the art in guitar research and to propose viable alternatives that will ultimately result in a louder and better sounding instrument. Discrete models of the instrument up to 4 degrees of freedom are also presented. Results from finite element analysis can be utilized for the evaluation of acoustic radiation. Introduction Classical guitars are unique musical instruments as the acoustic response of each piece of a particular model is different from another one although they are dimensionally identical and are all made by the same luthier according to French [1]. Two reasons given for this lack of acoustic consistency are firstly the variations in the natural properties of wood and secondly the manual tuning process of the soundboard by experienced luthiers which is not well understood analytically. Borland [2] has determined that humidity of air and moisture content in the wood are important factors affecting how wood responds when it vibrates. Technically, classical guitars have been modelled and analysed by using several mathematical models. These models were used for determining modal frequencies and frequency response function. Using these results, classical guitars can be objectively assessed by evaluating their acoustic radiation. Throughout the evolution of the classical guitar since AD, it is generally agreed among luthiers that the type of wood, the design and placement of bracings on the soundboard, and the reinforcement of the back plate play important roles in the production of a good acoustically radiating instrument. This consensus among luthiers creates an aura of mysticism that surrounds the construction of the guitars and translates into an enormous respect for top quality concert instruments. This intuitive analysis of the luthier can be reinforced by scientific knowledge through collaboration with research scientists in the fields of Mechanics of Solids and Continuum Mechanics. The research here centres on a combination of experimental and numerical research and the experience of a well-known luthier [3]. Studies by Richardson et al. Based on these findings, research on increasing the loudness of the guitar by focusing on the soundboard alone is a potential in future research. The objectives of this paper are categorically summarised under the following sections: Mathematical Models Section 3: Acoustical AnalysisThe above two categories define the scope of review in this paper. Mathematical Models Richardson et al. Factors that affect the performance of vibrating soundboards in terms of acoustic radiation are design, placement and arrangement of bracings, and thickness. These factors contribute to the musical acoustics of the classical guitar. An in-depth understanding of the dynamic characteristics of the classical guitar can be obtained by considering some mathematical models. In particular, the simplest two-mass model of Christensen-Vistisen [7] provides a simple understanding of the interaction between a vibrating air mass and the soundboard. This model and the three-mass and four-mass models are three classical examples of discrete mathematical models of this instrument. These models are based on the mass-spring-damper mechanism. As Richardson et al. This component, complete with design and arrangement of fan strutting, can then be assembled with the ribs and back plate to study the effects on modes and natural frequencies due to noncoupling between the soundboard and back plate versus coupling between these two components via the air mass inside the guitar body as was carried out by Elejabarrieta et al. Discrete and Continuous Systems 2. This model consisted of an air piston and the soundboard. Christensen [9] proposed a 3rd degree of freedom in the form of a back plate while Popp [10] proposed yet a 4th degree of freedom in the form of ribs. These are the 3- and 4-degree-of-freedom models, respectively. These additional degrees of freedom provided more realistic representations of the guitar. The range of frequencies investigated was 80â€" Hz. A hybrid mechanical-acoustic model proposed by Sali and Hindryckx [11] and Sali [12] was used to investigate the changes in loudness relative to the first peak the first resonance of the complete instrument. This model consisted of a mass, spring, damper, and a massless membrane rigidly attached to the mass. The membrane had a constant area equivalent to that of the radiating surface. Continuous Systems As the number of degrees of freedom increases, modelling using discrete masses becomes cumbersome. To circumvent this problem, the complete instrument can be considered as a continuous system and its vibration characteristics can be effectively analysed using the finite element method as shown by Derveaux et al. The soundboard can also be shown to satisfy the criterion of a thin plate in flexure and the application of the theory of thin plates results in a fourth-order partial differential equation of the vibrating system. Attempts to solve this model analytically can be researched using current mathematical methods. Vibration of the Complete Instrument Analytical models with 2-, 3-, and 4-degree-of-freedom have been formulated by Christensen and Vistisen [7], Christensen [9], and Popp [10], respectively, and are applicable to the complete instrument. Modal analysis of the 2- and 3-degree-of-freedom models by Caldersmith [15] and Richardson et al. Similarly, modal analysis of the 4-degree-of-freedom model also predicted three eigenvalues in the frequency range of 80 to Hz but a fourth eigenvalue was missing. It was concluded by Popp [10] that assigning a fourth-degree-of-freedom model in the form of a finite mass to the ribs does not introduce any new elastic restoring force and hence there is no fourth eigenvalue. Hence adding extra degrees of freedom beyond the fourth in this method of modelling the classical guitar would add unnecessary complications as even with the 4-degree-of-freedom model; the mechanics of the complete guitar body cannot be adequately represented [4]. Hess [16] conducted a parametric study with the two-mass model to identify a unique combination of physical parameters in an attempt to increase the sound level over a frequency range of 70 Hz to Hz. Although this investigation was performed on an acoustic guitar, there is no indication that these parameters could not be used to examine their influence on classical guitar soundboards. The range of frequencies of a classical guitar investigated by Czajkowska [17] varies from 70 Hz to just under 2 kHz. However, there are also harmonic notes that the classical guitar can produce. To account for these higher frequency notes, Richardson [18] suggested that the range of frequencies is extended to 20 kHz, which is the upper threshold of human hearing. However, from ISO For practical purposes, experiments could be conducted up to 5 kHz. Sakurai [19], a luthier, made some interesting video recordings of the vibration of the soundboard. He experimented with the traditional bracing structure and with diagonal braces and discovered that the soundboard could be made thinner and could vibrate with larger amplitudes without compromising on its structural integrity. However, there was no accompanying mathematical analysis. They further concluded that low-order modes have significant controlling influence on the playing qualities of the guitar. This conclusion was based on informal listening tests. Two-Degree-of-Freedom Model The simplest model consists of two masses representing the soundboard and an air piston as proposed by Christensen and Vistisen [7]. Hess [16] has shown that this model gives good agreement between theoretical and experimental results for sound pressure and acceleration frequency response at low frequencies 80 to Hz as shown in Figures 1 and 2. Comparison of theoretical and experimental results for sound pressure level at a distance of 2 m above the soundboard [16]. Comparison of theoretical and experimental results for acceleration per unit force [16]. The first resonance typically occurs within a frequency range of 90â€" Hz while the second can be found in the range of â€" Hz. The model provided excellent quantitative fit for both sound pressure versus frequency and acceleration versus frequency responses. Hologram interferometry by Richardson and Walker [21] has shown that the second mode is the lowest fundamental mode of the soundboard alone. The first resonance is found only in the complete instrument made up of the soundboard, back plate, ribs, and neck. This implies that there is coupling between the soundboard and the air mass inside the cavity of the guitar the Helmholtz resonator. Three-Degree-of-Freedom Model Christensen [9] proposed the addition of a third mass, the back plate of the guitar. The addition of a third degree of freedom depicts a more realistic guitar when it is played. Three resonant frequencies were obtained and the phase relationships between the soundboard, the back plate, and the air piston were obtained. Results from the first three resonances were obtained by Richardson and Walker [21] using holographic interferometry. That is, the bridge lies on an antinodal area since this is the location where the strings transfer vibration to the soundboard. Results for sound pressure versus frequency at the high frequency above Hz spectrum showed that radiation from the soundboard dominates radiations from the back plate and the sound hole when the instrument is driven directly using an impact hammer with no strings attached as shown in Figure 3. Monopole sound radiation from 3-degree-of-freedom model [4]. Therefore, if the soundboard can be made as thin as possible, then total sound radiation would increase. This is an important consideration for the classical guitar if the sound level from this instrument is to be increased. This is an attempt to quantify quality of the classical guitar. Global properties could be measured in terms of the -value of resonances. The -values could also be a parameter associated with quality of the instrument according to Richardson et al. Four-Degree-of-Freedom Model A 4-degree-of-freedom model by Popp [10] was used to gauge the relative importance of low-order modes in relation to midfrequency response. The stiffness of the soundboard and back plate were measured directly and their effective areas and masses were used to calculate the resonances and phases. Vibrations of the neck were shown to significantly affect the frequency response in some guitars. The calculated and measured resonances agree reasonably well as shown in Figure 4 and the relative phases between the air piston, back plate, and top plate are as shown in Figure 5. Isolated oscillator resonances for Kohno classical guitar [10]. Phase relationship for Kohno classical guitar [10]. Hybrid Mechanical-Acoustic Model This model was used to investigate the effects of brace positioning on the acoustics of the classical guitar in terms of loudness of tones based on the first resonant peak. This first resonant peak is a result of the coupling between the soundboard and the back plate via the air mass inside the guitar box. It was found that brace positioning had an effect on the peak amplitudes of the frequency response function. This model consists of a combination of mass, spring, damper, and a massless membrane as proposed by Sali and Hindryckx [11] and Sali [12]. This model was used to investigate the importance of the first mode on the tonal quality of the instrument. A comparison between good and bad quality guitars indicated that good quality guitars have lower frequency of the first mode and correspondingly higher amplitude in the frequency response function and lower or equal damping. This first mode corresponds to the first peak in the frequency response function of the instrument. It was found that the intensity or amplitude of the first mode was inversely proportional to the damping of the soundboard. The objective of this model was to optimize the placing of bracing for a better-quality instrument. Vibration of the Soundboard Investigation of soundboard vibration up to 10 kHz is best performed using finite element analysis. Sumi and Ono [24] conducted experiments with three different quality guitars and modal analysis using ANSYS showed that the best quality guitar had a thickness of 3.

Chapter 3 : Vibrations and Acoustic Radiation of Thin Structures - ISTE

Acoustic radiation and transmission by thin structures About the authors Paul J. T. Filippi was a Directeur de Recherche at the Laboratoire de MÃ©canique et d'Acoustique (LMA-CNRS, Marseille) until the end of

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