Intensity of Acoustic Radiation measurement on Persian Musical Instruments

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Introduction

Modal analysis is often considered quite important to describe the physics of Musical Instruments and their sound radiation. Nevertheless, several authors as Wogram, Suzuki and Giordano did not find strong correlation with modal analysis, and therefore further researches were requested.

A new acoustical parameter, called Intensity of Acoustic Radiation (IAR), was recently defined, and resulted very well related with mechanical vibration of sound source, being able to quantify the sound efficiency of musical Instruments In this paper the IAR was experimentally measured on Persian string musical Instruments. IAR relates mechanical vibration of surface (e.g. soundboards) and sound generation of the musical Instruments..

Sound radiation of Musical Instruments

The effectiveness of of a vibrating surface in generating sound power could be defined by the relationship:

$$\sigma = \frac{W}{\rho_0 c S \left\langle \overline{v_n^2} \right\rangle} \tag{1}$$

where W represents the sound power radiated by a surface with area S, which could be obtained by integrating the far-field intensity over a hemispherical surface centered on the panel, and $\left\langle \overline{v_n^2} \right\rangle$ represents the space-averaged value of the time-averaged normal distribution of velocity (Fahy, 1989). Sound radiation in the soundboard of string instruments have been studied by. Wogram, H. Suzuki and N. Giordano, ,using different measurement methods. Wogram used the parameter F/v, defining F as the excitation force and v as the resulting velocity at the point of excitation (1980). Suzuki used the "surface-intensity method" (1986), defined as:

$$I = \mathrm{Re}[p(\alpha / j\omega *)/2] \tag{2}$$

where I is the average intensity in time, perpendicular to the vibrating surface, measured in near field (about 30 cm from the radiating surface), and p and a are the pressure and the normal acceleration at the measuring point. Giordano used the parameter p/v, where p is the sound pressure measured in near field and v is the velocity of the soundboard (1998). Unfortunately in all these studies the resonance frequencies did not coincide with those of acoustic emission; on the contrary they often had negative correlation.

Intensity of Acoustic Radiation - IAR

IAR is defined as the space-averaged amplitude of cross spectrum between sound pressure caused by the movement of the vibrating surface of the musical instrument and the velocity of the vibration of the soundboard itself. IAR is therefore calculated in the following equation

$$IAR(\omega) = P(\omega) * V(\omega) \tag{3}$$

The measurements require an omnidirectional microphone, which should be located in a fixed position at about 25 cm over the instruments, which should correspond at about one-forth of the principal dimension of the instrument. Furthermore, the measurements should be conducted in a slightly reverberant room, where reverberation time helps to average radiation of sound caused by early modes. At higher frequencies the room acoustics do not influence the measurements. Moreover, the space-averaging of the data conducted by moving the transducers thorough the instrument enhance the measurements

The Persian Musical Instruments

Persian music utilises a wide number of musical instruments that are quite different from classical European ones. Many of them consist of a wooden sound chest made of local spruce, whereas the soundboard is often made of animal skin. For their characteristics, Persian musical Instruments could be considered closer to Indian instruments rather than European ones. In this work the measurements were conducted in three different Persian musical instruments, namely *Thar*, *Si-thar* and *Santoor*. These three musical instruments were made in an artigianal shop in Tehran, Iran, and bought directly to Europe.

Figure 1: The Iranian *Thar* in his original case

For all the instruments the measurements were made in a sligthly reverberant room, as required to proper consider sound generation of the instruments, since reverberation time helps to average the radiation caused from early modes. The following instrumentation was used:

- Hammer Brüel & Kjær type 8203

- Accelerometer Brüel & Kjær type 4374
- Two charge amplifiers Brüel & Kjær type 2635
- PC equipped with 20bit A/D converter soundcard and 8 channels 96 kHz sample rate.
- Soundfield microphone

In all the instruments, based on reciprocity theory, the accelerometer was located in few fixed positions on the bridges, whereas the soundboards were excited by the hammer in several positions.

Results

During the measurements, both acoustic pressure and velocity vibration were stored. Starting from the vibrational measures, modal analysis was obtained for the resonation frequencies up to 1 kHz. Moreover, as defined in (3), in a second step, IAR for all the three musical instruments was calculated.

The *thar*

In the *Thar* the soundboard is made of lamb skin, and it became therefore quite difficult to measure vibration. The *thar* is a double-heart-shape string Instruments made of wooden soundchest. The frequency response funcion measured in the thar is represented together with IAR and and impedance graph.

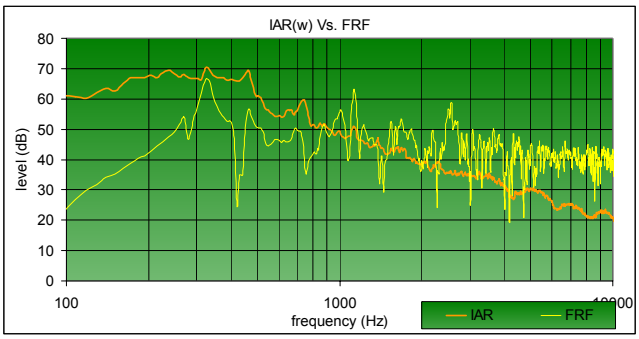

Figure 2: IAR compared with FFR for the Iranian *Thar*

The *Si-thar*

The Persian *Si-thar* differes from the Indian one because of his smaller dimensions and lamb-skin soundboard. As in the *thar,* the measurements on the soundboard required high precision and care on handling.

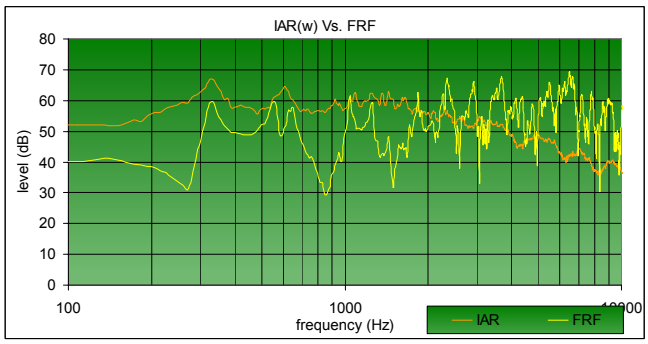

Figure 3: IAR compared with FFR the Iranian *Si-thar*

The *Santoor*

The *Santoor* is a string musical Instruments more similar to xilophone and clavichord, and moving the Instruments is easier than the others. However, even though the soundboard is wooden made and resistable, it becomes almost unfeasible to measure soundboard vibration in the soundchest, due to the high numer of strings and the possibility of moving the bridges.

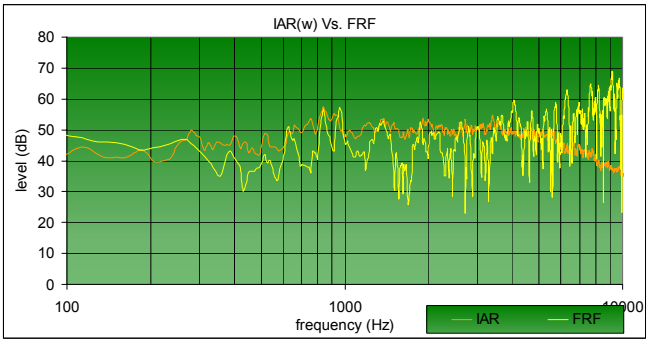

Figure 4: IAR compared with FFR for the Iranian *Santoor*

Conclusions

In all three musical Instruments the measurement of IAR is reported combined with FRF graphs. As a overall result, in all cases low-mid frequencies of IAR and FRF are closer each other, whilst al high frequencies the correlation is quite lower. *Thar* and *si-thar* have a similar resonance frequency at about 320 Hz, but differs noticeably at mid and high frequencies. The *santoor* produces a more equilibrate sound spectrum, dur to the high number of strings and a mor complex shape of the soundchest.

References

[1] F. J. Fahy, (1989). *Sound Intensity* Elsevier Applied Science, London.

[2] A. Farina, and F. Righini (1997). *Software implementation of an MLS analyzer, with tools for convolution, auralization and inverse filtering*, preprints of the 103rd AES Convention, New York, 26–29 September.

[3] N. Giordano (1998). *Sound production by a vibrating piano soundboard: Experiment* J. Acoust. Soc. Am. 104, 1648–1653.

[4] H. Suzuki (1986). *Vibration and sound radiation of a piano soundboard*, J. Acoust. Soc. Am. 80, 1573–1582.

[5] A. Tubis, and R.E. Davis (1986). *Kettle-shape dependence of timpani normal modes,* paper K2-7, 12th International Congress on Acoustics, Toronto.

[6] K. Wogram (1984). *Akustische Untersuchungen an Klavieren*, in Der Piano -und Fly¨gelbau Verlag Das Musikinstrument, Frankfurt; English version, *Acoustical Research on Pianos: Vibrational Characteristics of the Soundboard*, Das Musikinstrument.

[7] L. Tronchin (2005) *Modal analysis and intensity of acoustic radiation of the kettledrums*, J. Acoust. Soc. Am. 117(2), 926-933