Modal Analysis of the Persian Tar: Finite Element Modeling and Experimental Investigation

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Introduction

String instruments are systems of complex vibration, both in terms of structure and the fluid structure interaction. The string sound alone has a minor role in the sound output, since the radiated sound is mostly generated by the body and cavity of the instrument [1]; meaning that the whole instrument acts as a filter, converting the excitation force of the strings to sound and radiating it. For the instrument makers, it is practically impossible to get an optimal design for a string instrument and reproduce it using a particular manufacturing process. Consequently, fine tuning is an essential step in making any high-quality instrument, with tiny differences producing such huge change in the sound that it is noticeable even to a nonprofessional listener. In the lack of a scientific guideline, fine tuning of many musical instruments, including the tar, relies completely on the perceptual knowledge of luthiers, which is susceptible to unrepairable errors. Basically, fixing the problem often leads to new problems. However, having a reliable model makes the structural modification process faster, cheaper, and more insightful. After identifying the problematic notes on a particular instrument, the luthier can check the general modal map of the instrument and find the modes that are potentially causing the problems. Additionally, knowing the mode shapes gives a guideline as to which areas of the structure should be targeted to fix particular modes with minimal disturbance to other modes/frequencies. Knowing the modal properties of the tar is also a prerequisite if one wants to make "tonal copies" of a particular high-quality instrument. There is no scientific attempt found in the literature to analyze this type of instrument. As the Tar makers have historically followed what their masters had experimentally taught them, no scientific data has been derived and to the best knowledge of the authors, this study is a first reported attempt for a thorough analysis process.

The Tar Instrument

Tar is a long neck lute categorized as a plucked string instrument of the membrane type and can be traced back to 970 B.C. It has six strings in three double courses, commonly tuned as C4 (262 Hz), G3 (196 Hz) and C3 (131 Hz), although many players prefer to tune their instruments up to three semitones below these values. The frequency range is from slightly above 110 Hz to below 1000 Hz, depending on the type of melody played. In this instrument, the bridge sits directly on the membrane and therefore transfers the energy from the strings excited by the 3 cm brass pluck to the membrane. Hence, the membrane has a role similar to the sound board in guitar and violin. The total mass is 1550 gr.

The body is made out of white mulberry, carved by hand (treated as a sculpture). The membrane is either skin of a fish (without scales) or lamb (or stretched bladder). Figure 1 shows the various parts of the instrument. For Kamancheh, another membrane string instrument, it has been shown that the vibrations of neck and the box are in scale of 0.01 to 0.001 of the membrane vibrations (however, in that case, the scale could partly be intensified due to the sphere-like shape of the sound box) [2]. Although it would be acceptable to assume that the acoustic properties of tar are similarly dominated by the skin and the bridge vibrations, in this paper we focus on the body, supposedly creating the boundary for the enclosed air cavity.

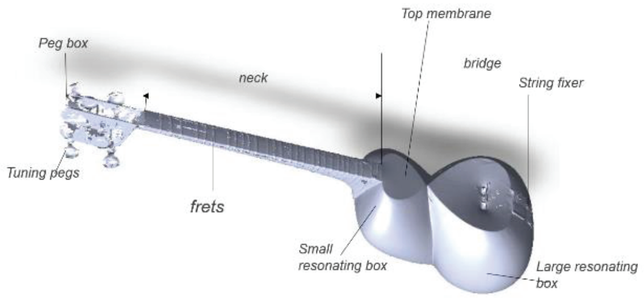

Figure 1: Schematic of a Tar

Experimental Setup

The setup consists of a mount to hang the instrument using strings (for the free-free boundary conditions), a roving impact hammer and a force transducer to measure the force at the point of application. Two accelerometers were glued by wax on the surface to capture the response of hitting 82 points, 10 hits averaged for each point.

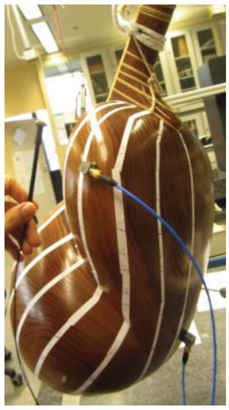

Figure 2: Experimental Setup

Setup details can be seen in Figure 2. Experimental modal analysis is performed on the instrument with focus on the body's vibration across a frequency range from 10 Hz to 1 kHz. Natural frequencies and vibration shape modes of the membrane were then derived in the frequency range.

Experimental Results

After geometry creation in MEScope, the directionality of the normal to the surface vectors were as well set. Modal Analysis was done and natural frequencies were derived using stability method of fitting. Frequency response can be seen in Figure 3. The mid-range vibration modes possess the natural frequencies of 208, 242, 419, 534, 632, 846 and 864 Hz. As an example for musical interpretation, the fifth mode (419 Hz) could be the ‘A’ note or the pitch standard which fits into the way it is tuned.

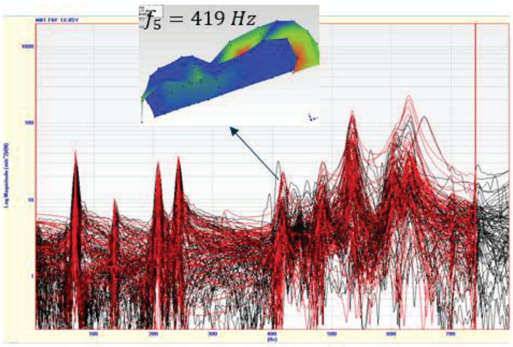

Figure 3: FRFs and the pitch standard frequency

Simulation

Surface geometry created by the points scanned with a 3D laser scanner was imported into ANSYS Workbench. Having discussed with instrument makers, uniform thickness of 8 mm was agreed upon as an average and was applied to the surface model. Although few studies have addressed the vibrational properties of wood used in membrane instruments, white mulberry (Morus alba) has been recently studied, especially the type that has gone through the curing process to be used as an instrument material. Therefore, orthotropic properties reported by Golpayegani et al [3] for similar type of wood were used, mesh was created with below 10000 elements and results were derived (Figure 4).

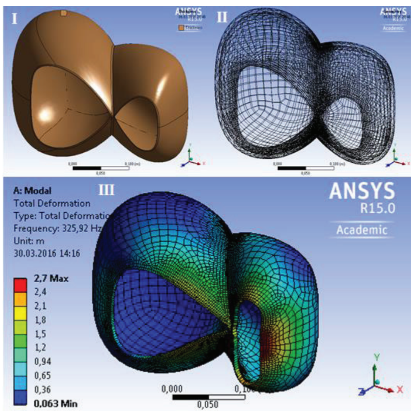

Figure 4: Simulation steps: (I) Geometry creation, (II) Meshing, (III) A sample deflection shape result

Comparison and Discussion

As can be seen in Figure 5, the frequencies of the main modes in the frequency range show an agreement of less than 4% difference. These are the modes for which the deflection shapes also show a general matching. This agreement between experimental and simulation results for the sound box confirms the possibility to model the instrument using the aforementioned method. Still, thickness distribution would have to be applied in a non-uniform way for the next stage, so that apart from the general mode shape, the local deflections and vibrational behavior would match better.

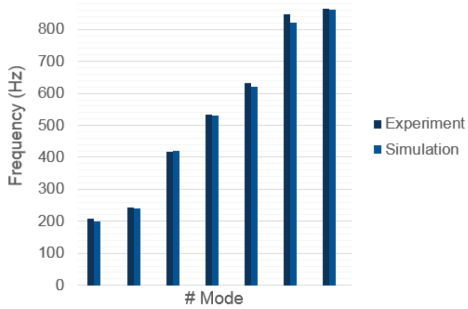

Figure 5: Modes of matching frequencies and deflection shapes; experimental and simulation results

Although local properties of the wood (random or not) were initially expected to interfere severely in the results, the fact that orthotropic property set for the wood resulted in acceptably matching deflection shapes gives the conclusion that the attempt to derive the modal map of the whole instrument would be possible.

Summary

The resonance box geometry of Iranian Tar was created by means of 3D laser scanning method. Experimental modal analysis is performed using the PAK impact hammer system. The dynamic responses measured are treated in a modal post–processing stage in MEScope. Natural frequencies and mode shapes are employed to compare with the simulation created in ANSYS Workbench and orthotropic mechanical properties were set according to the literature. Results of experiment and simulation give an acceptable match.

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