Technical Paper

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Modal Testing of a Soprano pan using a 3D Laser Doppler Vibrometer

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Abstract

Modal testing is a well established technique used to extract modal parameters such as natural frequencies, modal damping factors and vibration mode shapes from structures. Here, the technique is applied to a relatively new percussion instrument – the steelpan. The steelpan also referred to as the Caribbean steel drum or pan originated in Trinidad and Tobago during the Second World War. In this work modal testing is conducted on a soprano pan so as to obtain resonant frequencies and mode shapes as well as to provide a spatial illustration of modal tuning in the instrument. A soprano pan was excited with a periodic chirp signal from a loudspeaker and its response recorded by a 3-Dimensional scanning laser Doppler vibrometer. The results exhibit the nearly harmonic relationship among tuned modes in each outer note. There is also significant modal coupling between adjacent notes that have harmonically related frequencies.

Introduction

The steelpan has become the subject of much research over the last three decades with modal testing being used to explore the vibrational behaviour of the instrument. However, modal testing on steel pans has been mainly limited to the use of time averaged holographic interferometry and there is a plethora of studies which have used this technique to study the instrument [1-13]. This technique offers good spatial resolution but modal parameters such as damping cannot be directly obtained from this technique. Modal analysis has also been used extensively to explore the dynamic behaviour of a variety of other musical instruments [14-19].

Other modal testing techniques use sinusoidal excitation (either mechanical or acoustic) or impact excitation. Both techniques usually incorporate an accelerometer which is attached to the structure in order to detect vibration response. In modal testing with impact excitation, the structure is tapped at a number of points on a grid with a hammer having a force transducer. The force and acceleration data is used to create a transfer function on which several algorithms may be used to extract mode shapes and other modal parameters [20;21].

The major problem with these techniques is that the addition of the accelerometer can have the effect of reducing the values of the normal mode frequencies as well as adding damping to the structure. A mode may also go undetected if the accelerometer is located on one of its nodal lines. Although, mode shapes may be accurately determined, the spatial resolution offered by these techniques is usually poor.

In this study a 3D scanning laser Doppler vibrometer is used in conjunction with a loudspeaker. This technique, like time averaged holographic interferometry, also offers good spatial resolution in addition to providing data from which modal damping can be deduced. The technique also allows the vibration behaviour to be observed without any contact with the steelpan.

The steelpan – a brief history

The ***steelpan*** also known as the ***Trinidad pan*** or the ***Caribbean steel drum*** is a relatively new percussion instrument that was born from a process which was mainly influenced by the drumming traditions of West African slaves that were brought to Trinidad and Tobago to work on plantation estates. The early slaves played Congo drums which were eventually banned by the government out of fear that their usage would have incited an insurrection. However, love for music saw the emergence of another instrument which took the form of bamboo poles referred to as tamboo-bamboo, tamboo coming from the French word 'tambour' meaning drum. This was also banned as these bamboo poles easily became fighting sticks during clashes among rival bands. The people, having a profound passion for music began using garbage tins, dust-bins and car rims and car fenders as instruments for their music but this was short-lived as the expanding oil industry and the American Naval bases in Trinidad and Tobago provided a myriad of used oil drums which were used as a raw material for experimenting. The first steelpans took to the streets of Port-of-Spain in the Carnival celebrations a few years after the conclusion of World War II and since then the steelpan has evolved to become a family of instruments which include soprano or tenor pans, double second pans, cello, guitar and bass pans with a musical range that spans 5 octaves. A brief description on the manufacture of the steelpan can be found in the paper on the Aubrapan which is also a part of this conference proceeding. A comprehensive history of the instrument can be found in Blake [22]. In this work a soprano pan (see figure 1) is used as it contains the largest number of notes and it is likely to contain most of the vibration characteristics found on other types of pans.

Experiment

The musical instrument used in this investigation is a soprano pan manufactured and tuned by tuner and panist, Aubrey Bryan. The steelpan adopts the Trinidad 4th's and 5th's note layout in which the notes are arranged into three rings: the outer ring, the middle ring and the inner ring. C4 is the lowest frequency note on the pan. The experimental set-up used in this work is shown in figure 3.

For 3-dimensional measurement of motion, the soprano pan was mounted on an open chasis frame using foam wrapping to isolate the pan periphery from the frame surface. The loudspeaker was suspended beneath the frame to provide excitation. The steelpan was situated between the three tripod-mounted sensor heads and its surface was coated with a thin dusting of chalk powder (developer spray) to reduce light reflection and enhance scattering of the laser signal back to each of the sensor heads.

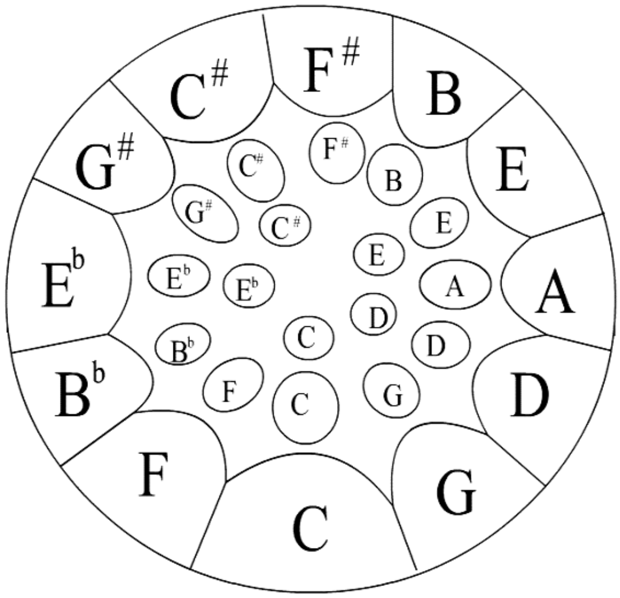

Figure 1: Note layout of soprano pan used in experiment

The steelpan vibrations were excited by the loudspeaker that played periodic chirp across the acoustic frequency region to excite all potential modes in the structure. A remote loudspeaker was chosen as this method of excitation precludes any modification of the structural response either locally or globally caused by physical contact with the pan surface by a striker or stinger connected vibrator. The loudspeaker excitation is also spread over the steelpan surface which resulted in an improved uniformity of excitation. Excitation was also more controllable because the loudspeaker was driven by a repeatable electrical signal from an incorporated function generator whose frequency matched the bandwidth and FFT settings of the Polytec 3D scanning laser system. Since the excitation was air coupled and some distance away from the drum surface, the volume needed to be high (approx. 95dB) for effective excitation. This made the conducting of the experiment impossible during normal work hours so the system was left to automatically scan and record the drum response during the late-evening.

The response of the pan was measured using a Polytec 3-Dimensional scanning vibrometer laser system which is comprised of three individual lasers or sensor heads that measure surface velocity from different directions (figure 3). This allows extraction of motion components along three perpendicular directions. The system measured in-plane (extensional) and out-of-plane (flexural) pan vibrations in the form of mobilities over the entire pan surface. The system also scanned the geometry of the steelpan dish.

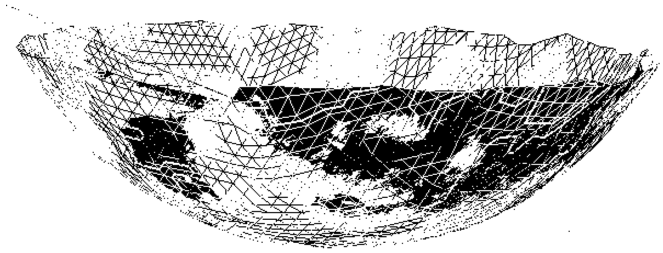

Figure 2: Scanned geometry of pan dish

The settings for the 3-Dimensional scan were for a frequency bandwidth of 5kHz with a resolution of 1.5625Hz (3200 FFT lines), measuring 7420 points with 5 averages. The measurement was successful with 99.8% of points returning an optimal quality status. The acquired vibration data was used to prepare animations of mode shapes for each of the note regions on the pan surface.

The laser vibrometer uses the Doppler effect to measure the frequency of the vibrating surface. The shift in the signal beam frequency (f_s) is related to the velocity (v) of the vibrating surface and the wavelength (λ) of the laser through the equation:

$$f_s = \frac{2v}{\lambda} \qquad \text{[Hz]} \qquad (1)$$

Figure 3: Set-up of the tri-laser system for the 3-dimensional scans of soprano steelpan

Results and Discussion

The first vibration modes of the C4# note region are shown in figure 4. The mode designation (m,n) will be used where m gives the number of radial nodes and n gives the number of circumferential nodes. The lowest or fundamental mode (0,0) at 276Hz represents the vibration of the entire note area in a single phase. The (0,1) mode was observed at 550Hz and the (1,0) mode at 640Hz. The 2nd and 3rd modes have frequencies at approximately 2.0 and 2.3 times the natural frequency of the fundamental mode. These ratios are an octave and approximately a major third above an octave. All other outer notes on the pan displayed the same mode shapes and frequency relationships. These first three modes are usually tuned into a harmonic relationship (see figure 6). In this case, the third mode does not fall into a harmonic series, but its ratio to the fundamental is nevertheless one which is pleasant to the human ear. Some tuners, are able to tune the third mode such that the ratio to the fundamental is 3:1.

Figure 4b also highlights another characteristic of the instrument. The fundamental mode (0,0) frequency of the $C5^{\#}$ note is the same as the (0,1) mode for the $C4^{\#}$ note. This is generally observed whenever modes have frequency values that are in close proximity. Figure 4c also illustrates this where the (1,0) mode of $C4^{\#}$ and the (0,0) mode of $E5^{b}$ vibrate at 640Hz. The (0,0) mode of the $E5^{b}$ is also observed at 632Hz.

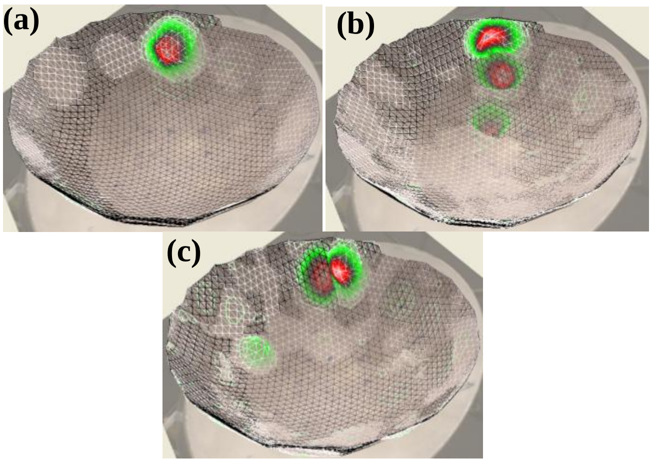

Figure 4: First three flexeural modes of $C4^{\#}$ note region: (a) 276Hz, (b) 550Hz and (c) 640Hz

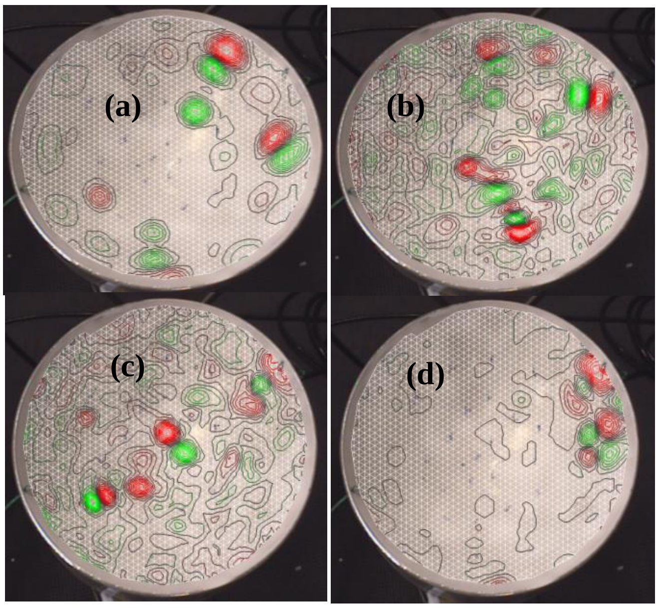

Figure 5: Modal Coupling in soprano pan: This is attributed to the presence of partials of the same frequency in different note regions: (a) 681Hz, (b) 1067Hz, (c) 1252Hz and (d) 1359Hz

All of the modes observed in the frequency range of interest were flexeural modes, indicating that the majority of sound produced from the instrument comes mainly from flexeural motions of the note regions. However, some radiation of sound is expected to occur from the pan side since it is coupled to the pan dish.

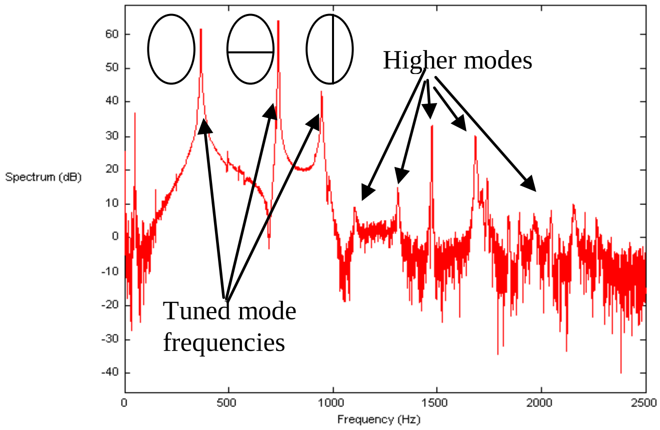

Figure 6: Typical frequency response spectrum for outer note on the soprano pan. First three modes are usually tuned into a nearly harmonic relationship. Higher modes are not harmonic but contribute to the overall timbre of the steelpan. Obtained using 1D scanning laser Dopler vibrometer and excitation using an impact hammer.

This study mainly observed mode shapes in the steelpan with the objective of understanding modal tuning but other useful information man be obtained by combining the measurements obtained in this study with other measurements, e.g. acoustic measurements. The information obtained from this investigation includes: normal mode frequencies, averaged mobilities (m/s/V) as well as flexeural and in-plane motion. Damping properties could also be easily extracted. Additional information such as radiation efficiency and radiation damping can be obtained with acoustic measurements. The 3D measurements also produces a 3-dimensional mesh of the steelpan which may be used to perform finite element simulations (see figure 2).

Conclusion

Modal testing of the soprano pan has provided a spatial illustration of mode tuning in the instrument. Pan-makers typically tune the first three modes of notes on the outer ring to have frequencies that form an approximate harmonic sequence. Only the fundamental mode is tuned in the middle and inner notes. There was also significant mode coupling among notes which contained partials of the same frequency. Although, modal testing of the steelpan is not new, modal testing with a 3D scanning laser Doppler vibrometer offers additional features which may be used in combination with acoustic measurements and finite element analysis to conduct a comprehensive investigation.

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