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MODES OF VIBRATION AND SOUND RADIATION FROM THE HANG

Andrew MORRISON[1], Thomas ROSSING[2]

[1] Illinois Wesleyan University
e-mail: amorriso@iwu.edu

[2] Stanford University

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The HANG is a new hand-played steel instrument developed by PANArt in Switzerland. We describe the modes of vibration, observed by holographic interferometry and the sound radiation from the instrument observed by measuring the sound intensity in an anechoic room by the two-microphone method. A low-voice HANG is compared with a high-voice HANG.

Keywords: HANG, sound intensity, steel instrument.

1. Introduction

The steel pan or steel drum originated after World War II when the British and American navies left thousands of 55-gallon oil barrels on the beaches of Trinidad. Originally a rhythmic instrument, local musicians discovered how to transform the steel pan into a melodious instrument by conditioning the metal and dividing the playing surface into note area that could be tuned. Steel bands are now found all over the World, especially in the Caribbean countries, North America, and Europe.

Steel pans, known by such names as tenor, double tenor, double second, guitar, cello, quadrophonics, and bass, cover a range of more than 5 octaves. The end of the drum is hammered ("sunk") into a shallow concave well, which forms the playing surface, after which the note areas are grooved with a metal punch. They are generally played with sticks wrapped with rubber. Most of the note areas sound at least 3 harmonic partials, tuned by skillful hammering [7].

In 2000, PanArt created a new hand-played steel instrument, which they called the HANG. It consists of two spherical shells, fastened together. Like the pang instruments, it uses nitrided steel. It quickly became very popular with percussionists, who learned to create a wide variety of sounds. In this paper, we will discuss the acoustics of this popular instrument.

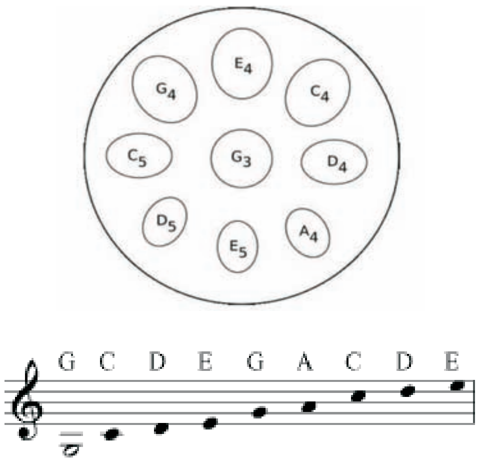
2. The HANG

The HANG is shown in Figure 1. The top (DING) side has 7 to 9 harmonically-tuned notes around a central deep note, which couples strongly to the cavity (Helmholtz) resonance of the body. The HANG is usually played in the lap, although it can also be mounted on a stand. The bottom side has a large hole (GU) which acts as the neck of the Helmholtz resonator. The resonator can be tuned by inserting a wooden collar (DUM) into the hole, thus changing its diameter and neck length, or by varying the spacing of the player's knees to change the acoustical "length" of the neck. A wide variety of bass tones can be achieved.

DING side GU side

Fig. 1. The HANG (DING side and GU side).

The HANG can be tuned in a wide variety of scales. The high-voice HANG we report in this paper had 9 notes tuned to a pentatonic scale, as shown in Fig. 2. This is the same HANG describe in an earlier paper [11]. Other scales are illustrated in Fig. 4. The low-voice HANG had 9 notes tuned to an Ake Bono scale with the lowest note at F3.



Eight elliptical note areas are arranged on the upper (DING) surface of the HANG around a center note area. The principal modes of vibration in each note area have frequancies in the ratio of 3:2:1 (except in the highest notes).

Fig. 2. Tuning of high-voice HANG used in these studies.

3. Modes of vibration

Each of the notes on the HANG has three tuned partials with frequencies in the ratios of 1:2:3. Modal analysis can be done by several methods, but the finest resolution is obtained using holographic interferometry. An electronic TV holographic interferometer is shown in Fig. 3. The object beam is projected on the HANG, and the reflected light is focused on the CCD array of a TV camera, while the reference beam is transmitted to the camera by means of an optical fiber. The resulting interference pattern is read out, pixel by pixel, and the holographic interferogram is constructed by a computer. Thus, an interferogram is created and updated at the TV frame rate (30 Hz in the United States). Figure 4 shows the high-voice HANG mounted on the air-supported optical table for holographic interferometry.

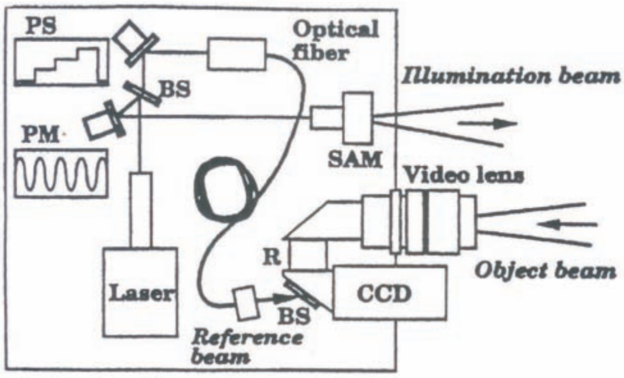


Fig. 3. Apparatus for electronic TV holography.

Five modes of vibration in the central G3 note area of the high-voice hang are illustrated by the interferogram in Fig. 5. In the (0,1) mode of lowest frequency, the entire note area vibrates with the same phase, while in the $(1,1)_a$ and $(1,1)_b$ modes a nodal line bisects the note area. The nodal lines in the two latter modes are orthogonal to each other, so they represent normal modes. These three modes at 189, 390, and 593 Hz have frequencies nearly in the ratio of 1:2:3. Also shown in Fig. 7 are the $(2,1)_a$ and $(2,1)_b$ modes having two nodal diameters and frequencies 1418 and 1543 Hz which are not harmonically tuned. The three lowest modes in the E4 note area, shown in Fig. 6, also have frequencies in the ratios 1:2:3, although the higher modes are quite different from those seen in the G3 mode.

The holographic interferograms in Fig. 5 serve as contour maps of the vibration amplitude. The "bull's eyes" represent the points of maximum amplitude, and each fringe (light or dark) represents a decrease in amplitude equal to $1/4$ of a wavelength of the laser light used (532 nm in this case). Information about relative phase is not recorded except that adjacent areas generally differ in phase by 180°. To recover phase data, we modulate a second mirror with a signal at the drive frequency having an adjustable phase. Then it is possible to obtain a phase map [2]. Phase maps are useful in studying coupling between note areas.

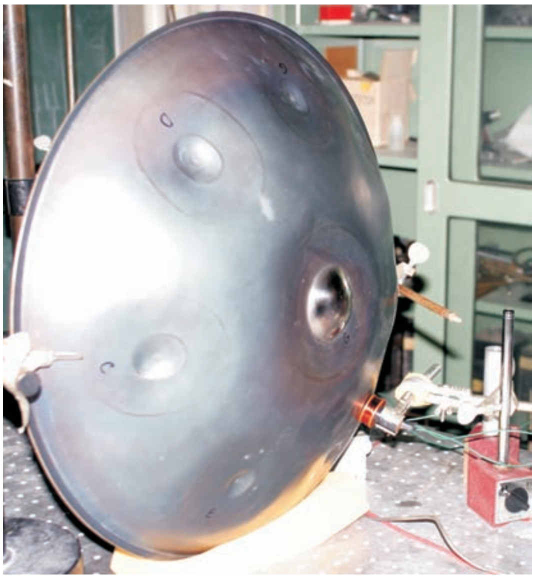


Fig. 4. High-voice HANG mounted on holographic table.

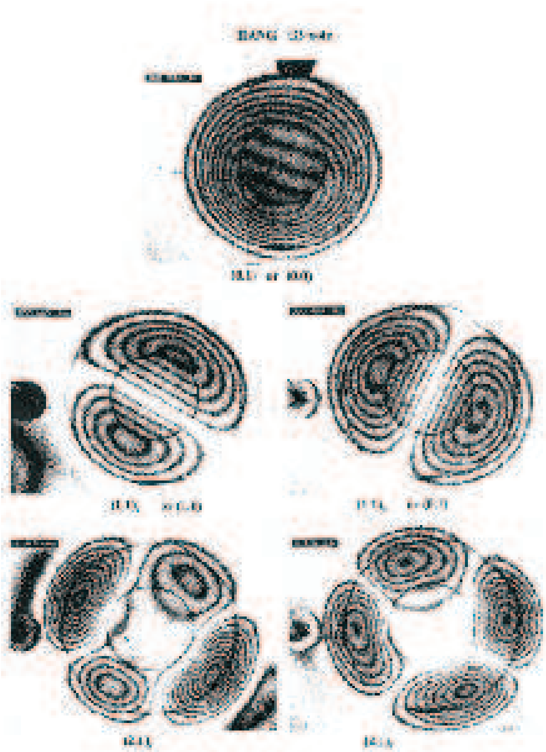


Fig. 5. Modes of vibration in the central G3 note area of the high-voice HANG.

Figure 6 shows phase maps of the D4 note area vibrating at its second resonance frequency (604 Hz) and the D6 note area vibrating at its lowest resonance frequency (also 604 Hz).

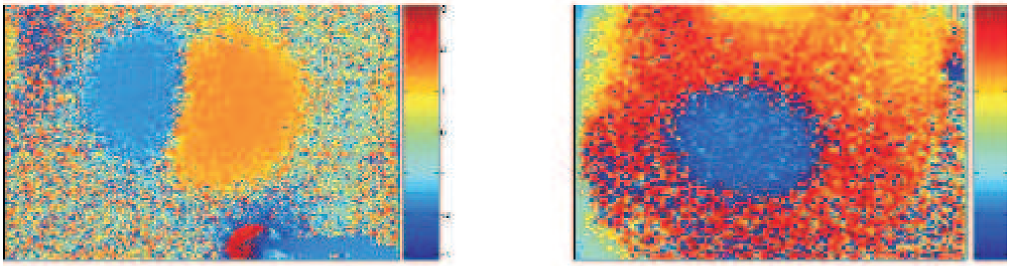


Fig. 6. Phase maps of the D4 note (left) at its second resonance frequency (604 Hz) and the D5 note (right) at its lowest resonance frequency (604 Hz).

Holographic interferograms of the low-voice HANG driven at small and large amplitude at frequencies near the first three resonance frequencies of the central F3 note are shown in Fig. 7. The mode shapes of the $(0,1)_{,}(1,1)_a$ and $(1,1)_b$ tuned in the ratios 1:2:3 are similar to those shown in Fig. 7. The coupling between various notes can also be seen. At 348 Hz, for example, the F4 note is strongly driven and the F4# is weakly driven, while at 520 Hz the $(1,1)_a$ mode in the C4 note and the (0,1) mode in the C5 note show appreciable response.

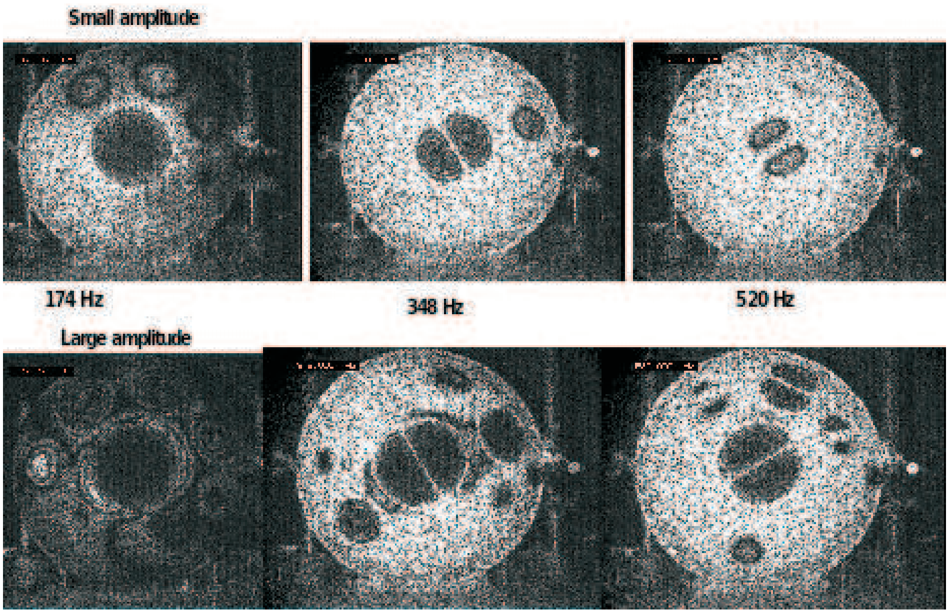


Fig. 7. Low-voice HANG driven at frequencies near the first three resonances of the central F3 note. Upper hologram at each frequency shows small driving amplitude, lower hologram shows large amplitude.

In Fig. 8 the low-voice HANG is driven near the first three resonance frequencies of the F4# note. The (0,1), $(1{,}1)_a$, and $(1{,}1)_b$ modes are shown, along with coupling to the $(1{,}1)_a$ mode of the C5# note.

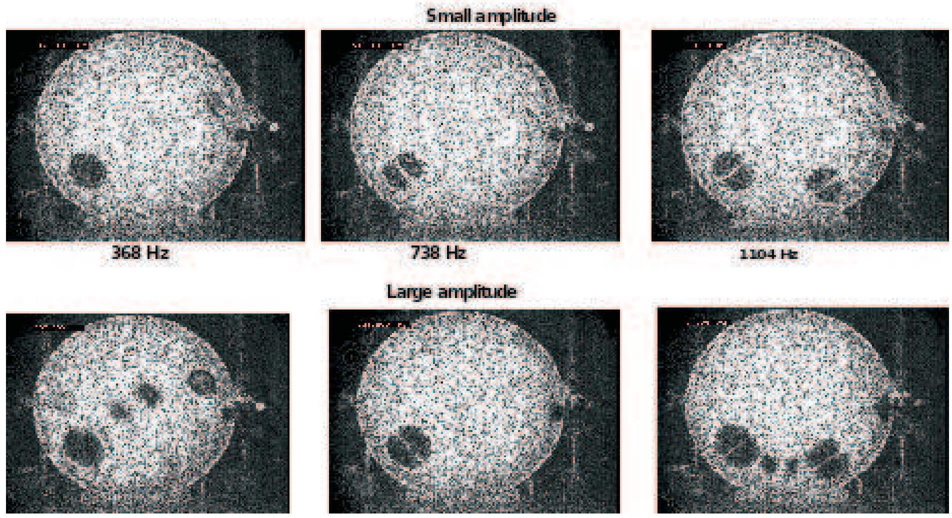


Fig. 8. Low-voice HANG driven at frequencies near the first three resonances of the F4# note. Upper hologram at each frequency shows small driving amplitude, lower hologram shows large amplitude.

4. Sound intensity

A convenient way to describe the acoustic field of a sound source is by accounting for the flow of acoustic energy outward from the source. The acoustic power density through a surface is called the sound intensity **I**. Complete theoretical treatments of sound intensity in monochromatic fields are widely available [3, 4]; only a brief summary is presented here for reference. The instantaneous intensity is the product of sound pressure $p(\mathbf{r}, t)$ and acoustic velocity $\mathbf{u}(\mathbf{r}, t)$:

$$\mathbf{I}(\mathbf{r}, t) = p(\mathbf{r}, t)\mathbf{u}(\mathbf{r}, t). \tag{1}$$

For a source vibrating at frequency ω, the instantaneous pressure is

$$p(r, t) = P(r)\cos(\omega t - \varphi(r)). \tag{2}$$

The acoustic velocity is

$$u(r, t) = \frac{-1}{\rho}\int \nabla p dt, \tag{3}$$

where ρ is the air density. Substituting (2) into (3) yields

$$u(r, t) = \frac{1}{\omega\rho}P(r)\nabla\varphi(r)\mathrm{cos}(\omega t - \varphi(r)) - \frac{1}{\omega\rho}\nabla P(r)\mathrm{sin}(\omega t - \varphi(r)). \tag{4}$$

The instantaneous intensity can be written:

$$p(r,t)u(r,t) = \frac{1}{\omega\rho}P^2(r)\nabla\varphi(r)\cos^2(\omega t - \varphi(r)) \\ - \frac{1}{\omega\rho}P(r)\sin(\omega t - \varphi(r))\cos(\omega t - \varphi(r)). \quad (5)$$

The sound intensity can be written as the sum of the active intensity (AI) and the reactive intensity (RI), which are in quadrature: $\mathbf{I}(r,\ t)$ = $\mathbf{A}(r,\ t)$ + $\mathbf{R}(r,\ t)$. $\mathbf{A}(r,\ t)$ is associated with the component of $\mathbf{u}(r,\ t)$ in phase with p. The time-averaged form of the AI component is the power flux, while RI represents power stored in the near field. A vector field plot of AI shows vectors pointing in the direction of power flow, while RI vectors show the stored energy flux close to the sound source. The RI component of total intensity drops off as distance from the source increases, falling to zero in the far field [1].

Intensity measurements of the sound field of the HANG were made in an anechoic chamber. A frame of aluminum tubing was suspended from the ceiling to support the instrument and the driving apparatus. An Ono Sokki CF-6410 sound intensity probe and a CF-360 FFT analyzer were used to measure the sound intensity at various planes near the HANG. The sound intensity probe consists of a pair of matched microphones with a spacing of 7 cm between them. The probe and analyzer allow for simultaneous acquisition of AI and RI. A good approximation to acoustic velocity is obtained from the pressure difference between the microphones as they move in the sound field.

Active intensity measurements in a plane 8 cm above the top (G3 bass note) of the high-voice HANG are shown in Fig. 9. In the top row, the D4 note was excited by a swept-sine signal ($0 \leq f \leq 2000$), and the intensity fields at the lowest three resonance frequencies were mapped over a 10×10 grid with 7 cm spacing between adjacent points. In the second row, the E4 note was similarly excited, while in the third row the A4 note was excited.

The active intensity maps show monopole radiation characteristics at the fundamental and second harmonic frequencies. The intensity field at the fundamental frequency exhibits a peak in AI directly over the note being driven. The intensity field at the second resonance frequency shows the largest active intensity region to be centered over the instrument and distributed over a large portion of the instrument. The intensity field at the third resonance frequency exhibits a dipole pattern.

Reactive intensity measurements in the plane 8 cm above the HANG are shown in Fig. 10. As in Fig. 9, the D4 (top row), E4 (middle row), and A4 (bottom row) notes were excited over the frequency range of 0 to 2000 Hz. The reactive intensity fields show a circulatory pattern at all three resonance frequencies. The RI shown is the peak value per cycle. Half a period later, the vectors have reversed their direction. For the three modes measured, the RI aligns mostly in a circulatory pattern which suggests an exchange of energy between the front and back of the instrument.

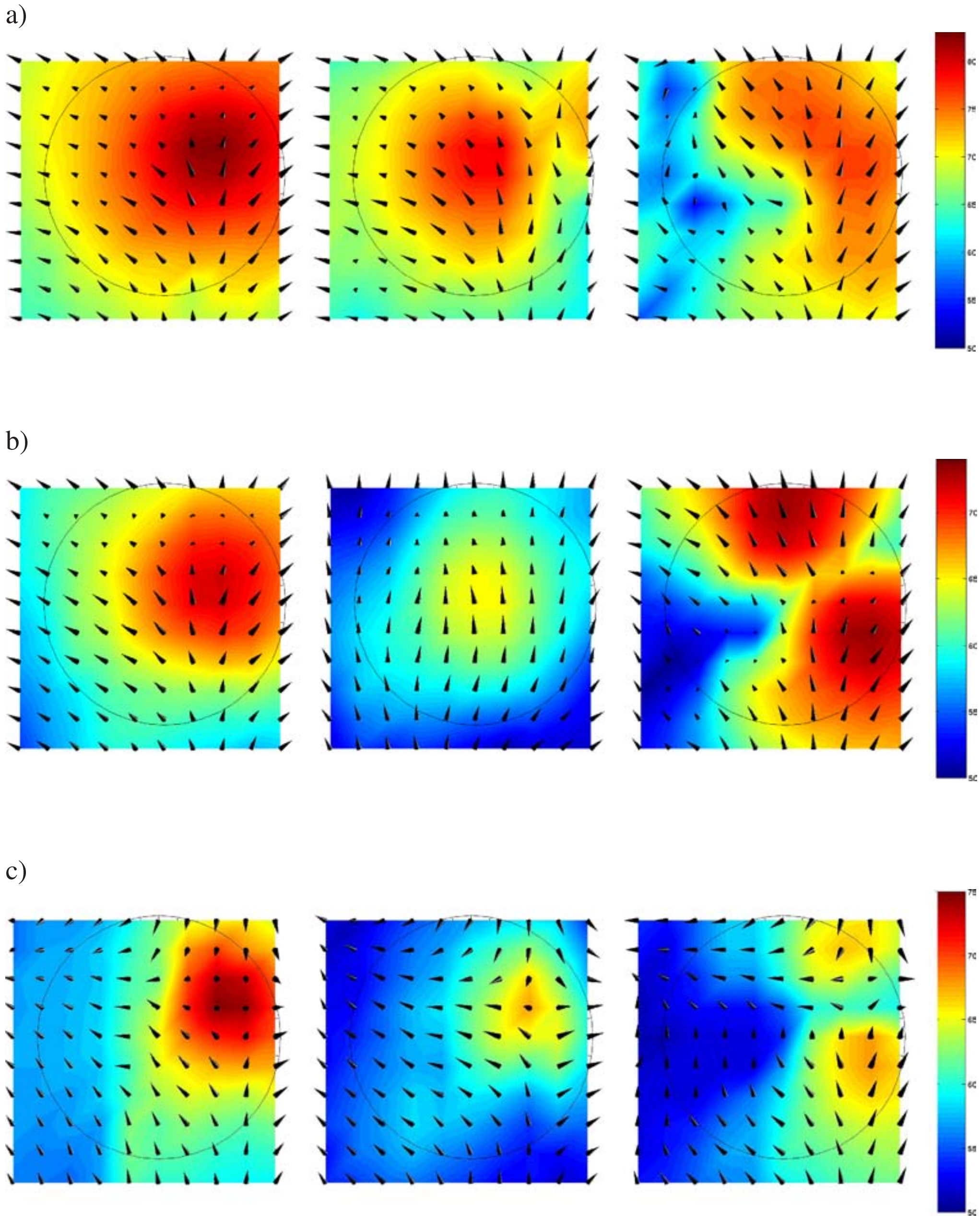


Fig. 9. Active intensity plots in a plane above the top of the HANG at the first three resonance frequencies of various notes of the HANG: (a) D4, (b) E4, (c) A4.

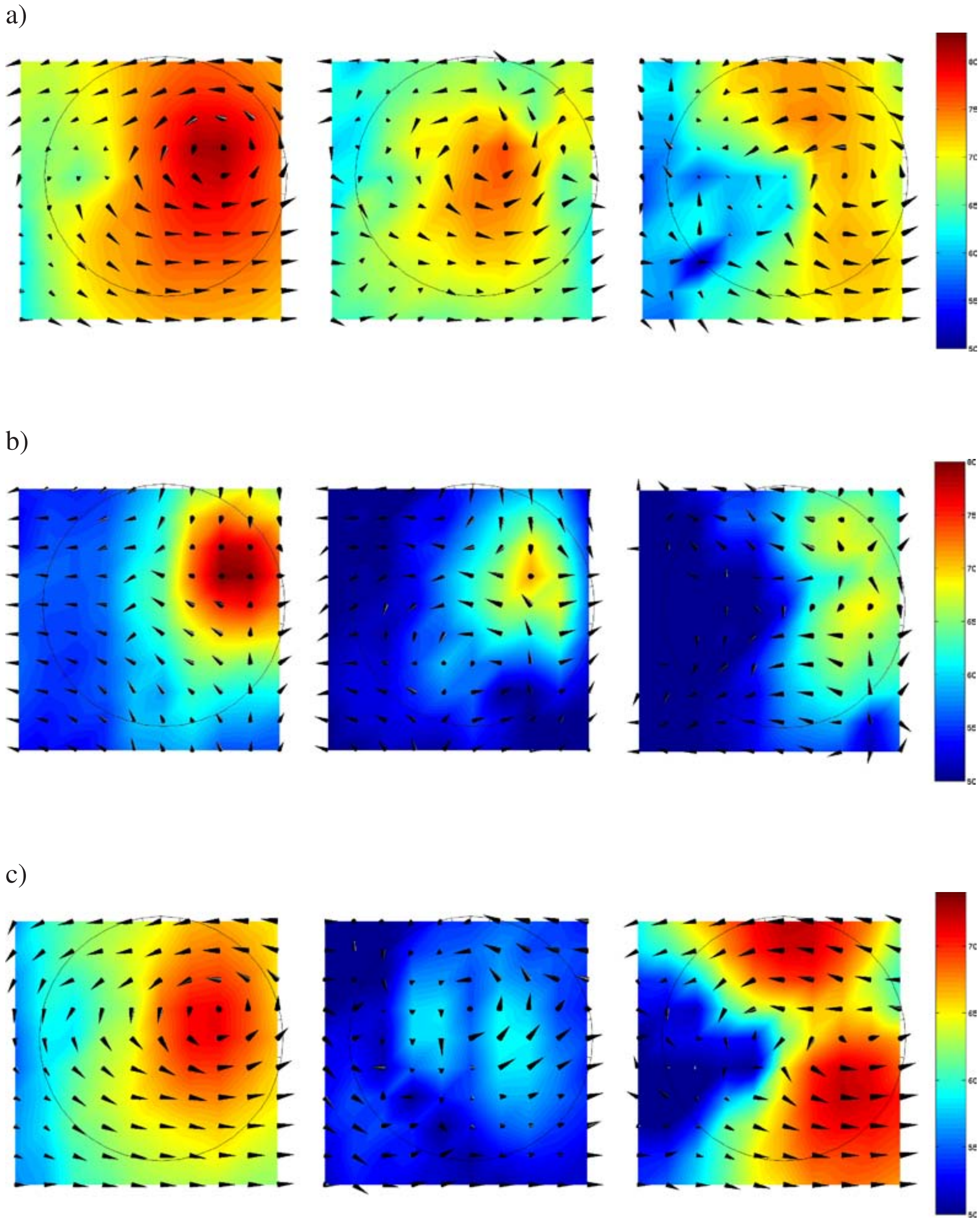


Fig. 10. Reactive intensity plots in a plane above the top of the HANG at the first three resonance frequencies of various notes of the HANG: (a) D4, (b) E4, (c) A4.

5. Conclusion

The HANG is a new hand-played steel instrument which has caught the fancy of many percussionists worldwide. Through experimenting with playing technique, performers have created many new sounds, and continue to do so. Understanding the modes of vibration and the sound radiation from the instrument help them to do so, as well as adding to our knowledge of the science of musical instruments.

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