ACOUSTICS OF THE HANG: A hand-played steel instrument

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Abstract

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. A low-voice HANG is compared with a high voice-HANG.

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 [Rossing, 2000].

As steel bands became more sophisticated, several developments took place in steel instruments. Tuners preferred new barrels to used ones, and they selected barrels with the most desirable steel composition and gauge. Scientific studies of steel pans helped to guide the pan makers, and musicians, scientists and makers worked hand in hand to improve the instrument [Rossing, Hampton, and Hansen, 1996]. It was discovered that "nitriding" (surface hardening) the steel created a hard, durable playing surface with a softer core that could be readily tuned. The pang family of surface hardened steel instruments was created that included the ping, peng, pong, and pung [Rossing, Hansen, Rohner and Schärer, 2000; Rossing, 2001].

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. Another paper at this conference [Rohner and Schärer, 2007] describes the design, construction, and tuning of the latest version of the HANG. In this paper, we will discuss the acoustics of this popular instrument.

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 resonanator. The resonator can be tuned by inserting a 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. Some playing techniques are illustrated in Fig. 2.

DING side GU side

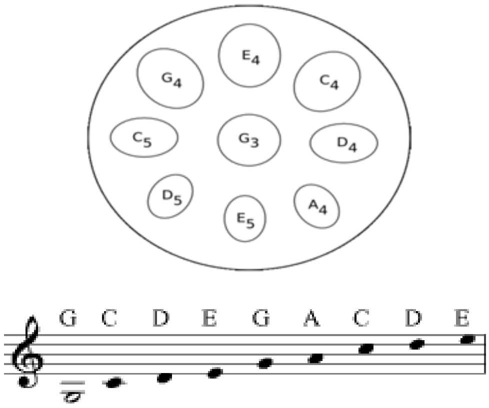
Figure 1: The HANG (DING side and GU side)

GU Exciting the bass Softly striking the DING

Changing the size of the GU DUM DUM in the GU

Figure 2: Some playing techniques for the HANG

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. 3. This is the same HANG describe in an earlier paper [Rossing, Hansen, Rohner, and Schärer, 2001]. 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, one note lower than the Ake Bono scale shown in Fig. 4.



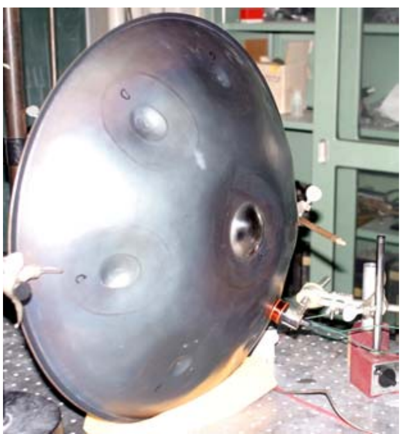
Eight elliptical note areas are arranged on the upper (DING) surface of the HANG around a center note area. The principal modes of vibration in each note area have frequencies in the ratio of 3:2:1 (except in the highest notes).

Figure 3. Tuning of high-voice HANG used in these studies

Figure 4: Other HANG scales

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.5. 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 6 shows the high-voice HANG mounted on the air-supported optical table for holographic interferometry.



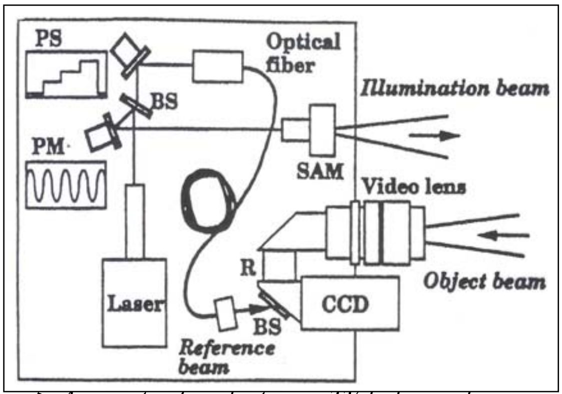


Figure 5. Apparatus for electronic TV holography mounted on holographic table

Figure 6. High-voice HANG

Five modes of vibration in the central G3 note area of the high-voice hang are illustrated by the interferogram in Fig. 7. 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 Hz, 390 Hz 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 Hz and 1543 Hz which are not harmonically tuned. The three lowest modes in the E4 note area, shown in Fig. 8, also have frequencies in the ratios 1:2:3, although the higher modes are quite different from those seen in the G3 mode.

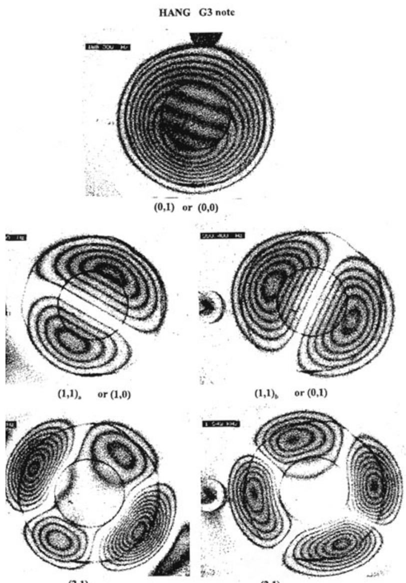


Figure 7. Modes of vibration in the central G3 note area of the high-voice HANG

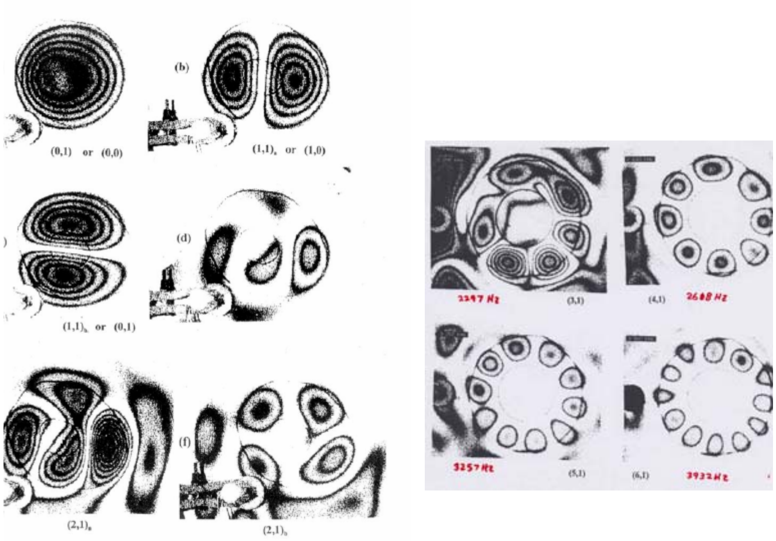


Figure 8. Modes of vibration of the E4 note area of the high-voice HANG

The holographic interferograms in Figs. 7 and 8 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 ¼ 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^o. 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 [Engström, 1996]. Phase maps are useful in studying coupling between note areas.

Figure 9 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).

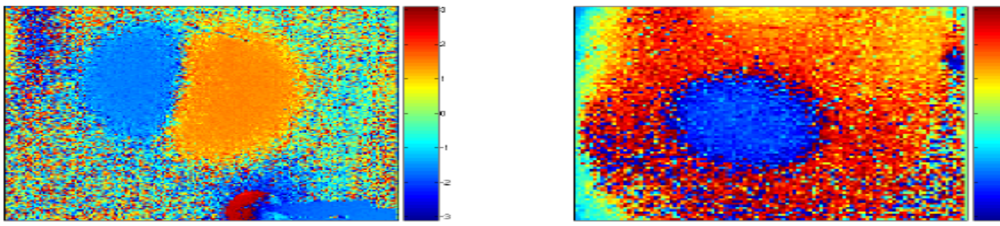


Figure 9. Phase maps of the D4 note at its second resonance frequency (604 Hz) and the D6 note at its lowest resonance frequency (604 Hz) Color bars indicate phase in radians.

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. 10. 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.

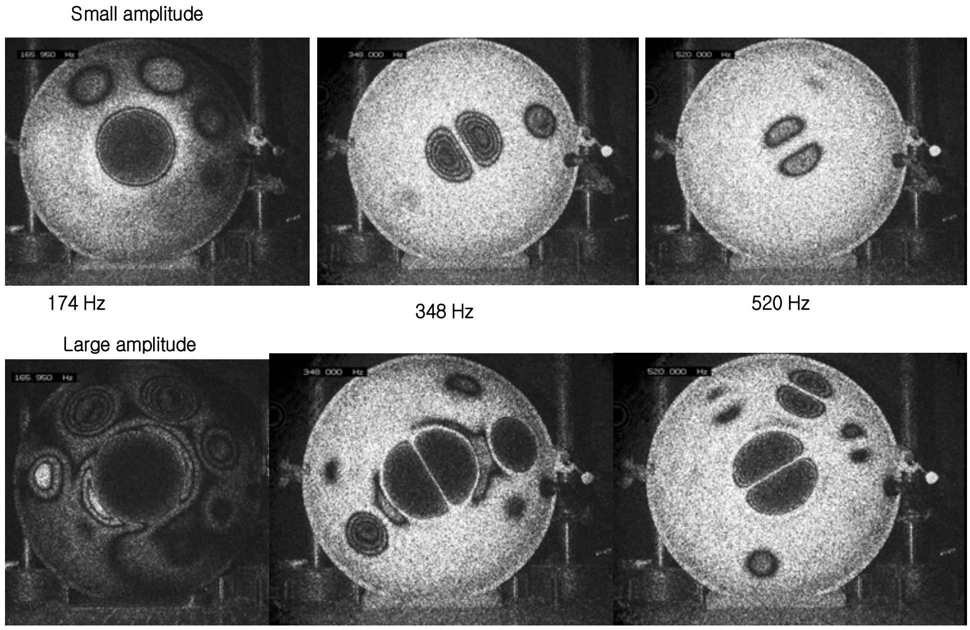


Figure 10. Low-voice HANG driven at small and large amplitude at frequencies near the first three resonances of the central F3 note

In Fig. 11 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.

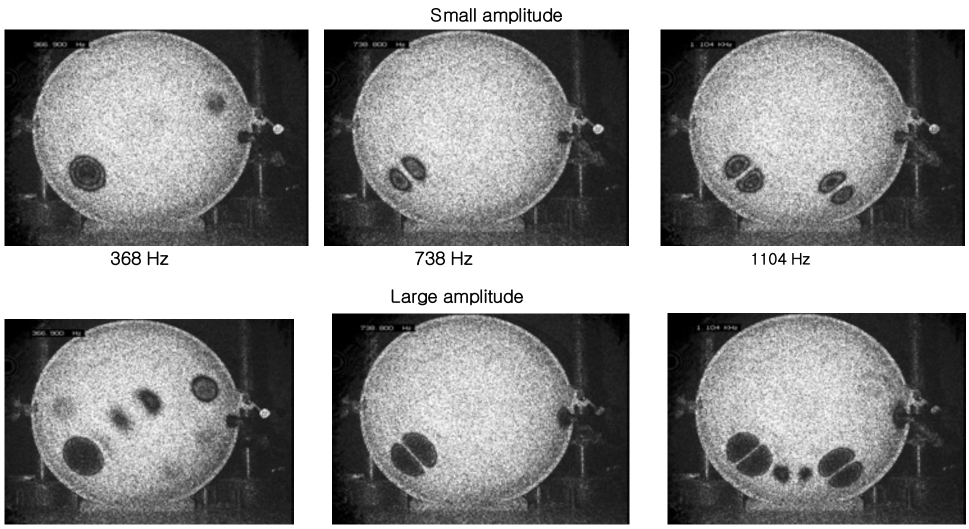


Figure 11. Low-voice HANG driven at small and large amplitude near the first three resonances of the F4# note.

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**. The instantaneous intensity is the product of sound pressure p(r,t) and acoustic velocity **u**(r,t). **I**(r,t) = p(r,t) **u**(r,t). The sound intensity can be written as the sum of the active intensity (AI) and the reactive intensity (RI), which are in quadrature: **I**(r,t) = **A**(r,t) + **R**(r,t). **A**(r,t) is associated with the component of **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 [Copeland, Morrison and Rossing, 2005].

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. 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. 12. The A4 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 10x10 grid with 7 cm spacing between adjacent points.

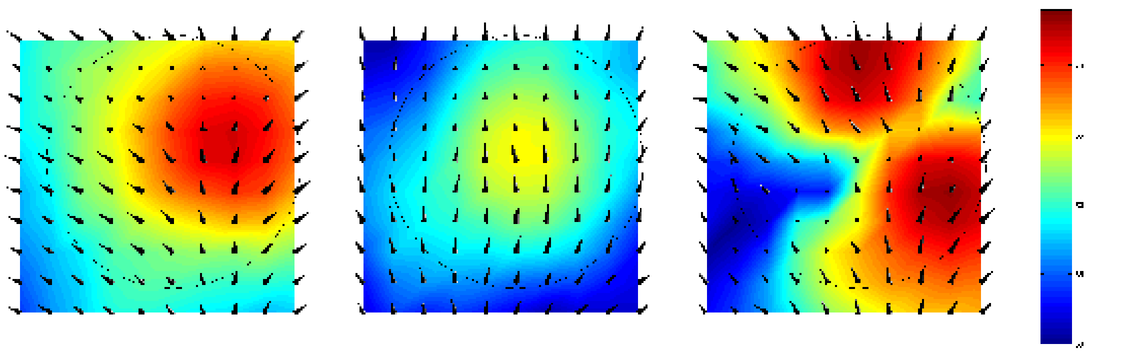


Figure 12: Active intensity 8 cm above the center of the high-voice HANG

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. 13. 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.

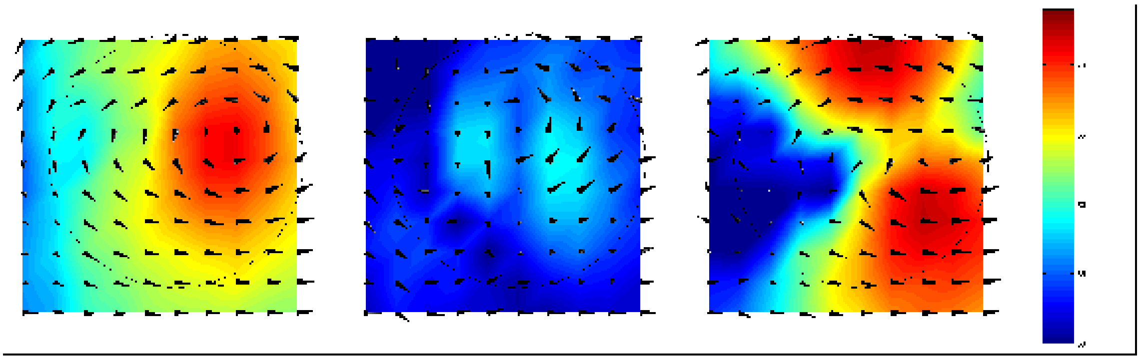


Figure 13: Reactive intensity 8 cm above the center of the high-voice HANG

The intensity fields above the E4 and D4 notes were also measured and found to the similar to the intensity fields above the A4 note [Morrison, 2006].

CONCLUSIONS

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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