

The extraordinary sound of the hang

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An increasingly popular percussion instrument created less than 10 years ago has inspired musicians and physicists alike to explore its sonic properties.

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A cousin of the Caribbean steel pan, the hang (pronounced “hung”) is a percussion instrument whose tuned notes are struck by a performer’s hands. The hang, made by PANArt in Bern, Switzerland, has a devoted following. Its name means “hand” in the local Bernese dialect. If you have yet to hear the instrument’s sound, you should go to YouTube, search for “hang drum,” and enjoy a few performances by amateur and professional musicians.

PANArt has a long history of making steel instruments and pioneered a nitriding technique for hardening the steel that it uses in its drums. The inspiration for the hang came when a percussionist looking for new sounds visited the drum builders at PANArt. The builders realized they could put two pan-like shells together to create a steel instrument that could be held in a musician’s lap and played by hand. After further development, they created a new instrument with a full, resonant sound. But the hang is not solely of musical interest; it offers a wealth of interesting physics that makes for rich acoustical study.

The hang, like the steel pan, has individually tuned notes embedded into the surface of the steel out of which it is constructed. Most hang drums have eight or nine notes arranged in a circle around the top of the flying-saucer-like shape of the instrument. Some of the notes are visible in panel a of the figure. In the center of the drum is the lowest note of the instrument, usually an octave below the lowest of the circumferential notes. Striking that center note excites a deep Helmholtz-like cavity resonance whose pitch can be adjusted by having the performer change the spacing between his or her knees.

When struck with the hand, each note area of the hang vibrates in a rich complement of modes. In particular, the three lowest-frequency modes—the fundamental and the second and third harmonics—are all strongly excited. The frequencies of those modes are in the ratio of 1:2:3, and that harmonic relation leads to an interesting effect: Striking one note can cause another note to vibrate. The waves created when the hang is struck are not confined to a single note area. Rather, they initially propagate outward through the steel of the instrument and are eventually reflected many times off the hang’s boundaries. If any other notes have resonances at frequencies near those in the spectrum of the struck note, as is often the case, then modes of the other notes will be excited and the hang will vibrate at the corresponding frequencies.

Visualizing the modes

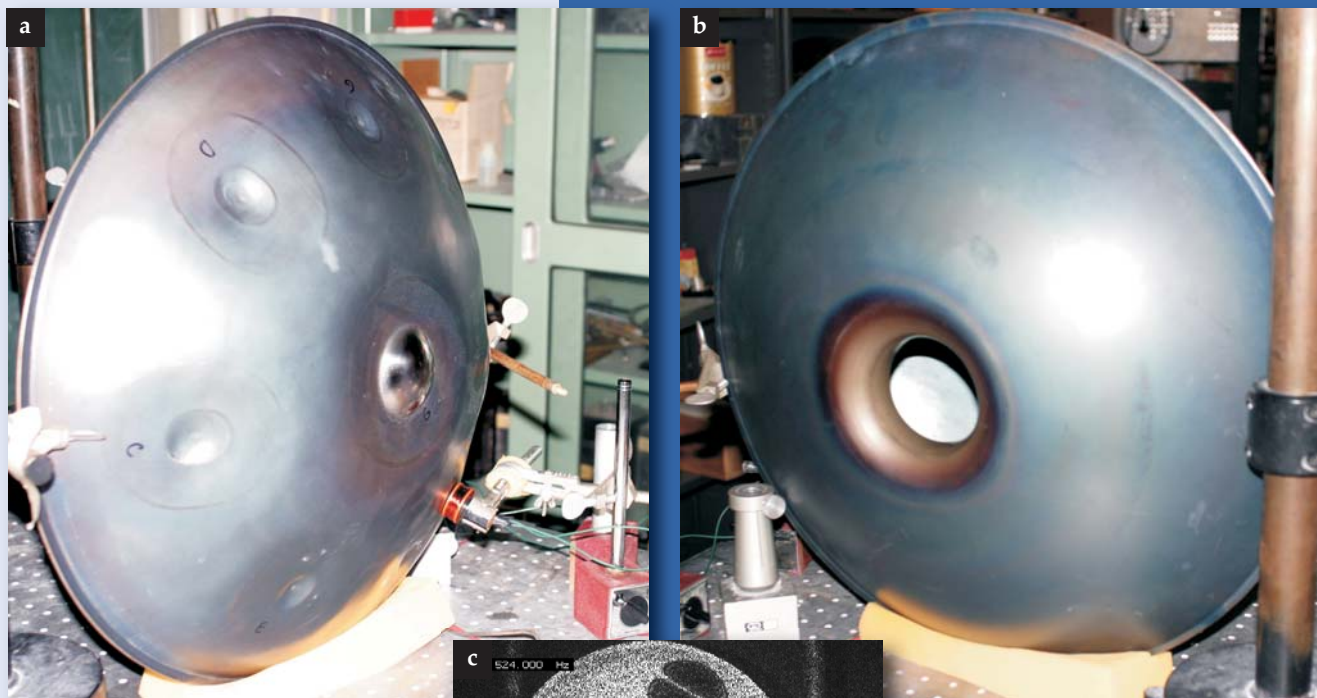
Modal analysis determines the vibrational modes of a structure. It thus allows one to look for consonant intervals—intervals whose frequencies are in simple whole-number ratios—and to check whether modal frequencies in one note area actually match those of notes in another area; if so, those other notes can be easily excited by resonance coupling.

A useful modal-analysis tool is holographic interferometry, which enables one to obtain the frequency and a contour map for each of the hang’s modes. The experimenter puts a small magnet near a note on the hang and places a coil near the magnet, as illustrated in the figure. By running an alternating current of a specified frequency through the coil, one creates an alternating magnetic field. That field pushes and pulls the small magnet and causes the hang to vibrate at the same frequency as the alternating current. Larger amplitude vibrations can be obtained by increasing the current through the coil.

A TV holographic interferometry system uses coherent laser light, split into two beams, to reveal the vibration patterns. Those patterns, often called mode shapes if the object is vibrating in one of its normal modes, are displayed essentially in real time on a TV monitor. As the frequency and amplitude of the drive signal are varied, the resulting change in the vibration can be seen immediately on the monitor.

Panel c of the figure shows an interferogram of a hang being driven sinusoidally at 524 Hz on the C_5 note area. That area is near the 6 o’clock position in the panel, which also shows the driving coil next to the note. At 524 Hz, C_5 vibrates in its fundamental mode, as manifested by the single circular lobed structure covering the entirety of the note. On the opposite side of the drum is the C_4 note, an octave lower than C_5 . It vibrates in its second mode, visible as a double-lobed structure. The bass note F_3 , a fifth below C_4 , vibrates in its third mode; that mode, too, is visible as a double-lobed structure. What distinguishes the second and third modes is the orientation of the nodal line that appears in the interferogram as a bright white line running through the note. The interferogram also reveals small vibrations around the 4 o’clock and 5:30 positions, which correspond to the notes C_5^+ and A_4^+ , respectively. The contributions of those notes at 524 Hz would be most significant for high-amplitude excitation. For the case at hand, their vibrations are unimportant compared with those of the other three notes visible on the interferogram.

Commercial TV holography systems tend to be expensive. At a fraction of their cost, however, one can build a so-



called electronic speckle pattern interferometer. ESPI and holographic interferometry use slightly different processing routines to reveal the mode shapes of vibrating objects, but the data they collect are essentially the same.

Sound intensity

Part of the energy emitted by a struck hang is radiated outward and some is stored in the near field as potential energy. By carefully examining the energy flow in the near field, one can separate out those radiated and stored components. In practice, one determines the sound intensity $\mathbf{I}(\mathbf{r}, t)$, that is, the product of the scalar sound pressure p and the vector acoustic flow velocity $\mathbf{v}$, the velocity of packets of air. Sound pressure is easily measured with an ordinary pressure microphone. With two accurately spaced microphones, the acoustic flow velocity can be calculated from the pressure gradient.

A two-microphone probe can measure only a single component of $\mathbf{I}$. To get intensity components in all directions, one turns the probe and repeats the measurement. Completing the procedure for a single plane of points located in a square grid of n points on a side requires a total of $3n^2$ measurements. Although a single measurement takes only a few seconds to record, positioning the microphone in the same location for each direction at all points on the grid can make for a long data collection process. No doubt that's why many researchers use microphone arrays that include as many as a few hundred microphones.

The sound intensity has units of W/m^2 and can be written as the sum of an active intensity $\mathbf{A}(\mathbf{r}, t)$ and a reactive intensity $\mathbf{R}(\mathbf{r}, t)$. In the expression $\mathbf{I} = \mathbf{A} + \mathbf{R}$, $\mathbf{A}$ is associated with the component of $\mathbf{v}$ that is in phase with p . Its time average is the radiated power flux. The reactive intensity, on the other hand, represents power stored in the near field.

By examining the modes of vibration and the sound intensity fields of the hang, physicists can gain a better understanding of how the instrument produces its distinct sound.

The hang and its mode shapes. Top (a) and bottom (b) views of the hang. Visible on the top of the hang are several notes embedded in the instrument's steel surface. Attached to the top surface is a tiny orange magnet. A nearby coil in a white housing drives the magnet for modal analysis. The cavity visible on the bottom view is associated with the instrument's lowest note. (c) This holographic interferogram was created when the note at

about the 6 o'clock position was driven at its fundamental frequency of 524 Hz. Notes near 12 o'clock and at the center of the hang show characteristic two-lobed excitations. The other two excitations, between 3 and 6 o'clock, are less significant. (The interferogram is adapted from a talk given by Tom Rossing at the 2007 International Symposium on Musical Acoustics; see <http://www.hangblog.org/panart/2-S2-4-IsmaRossing.pdf>.)

Such investigations also advance the science of musical instruments generally. The types of studies sketched in this article are by no means the final word on the subject. Indeed, PANArt has announced that it will take a break from making hangs in 2009 so that it can develop a new generation of its signature instrument.

Further reading

- T. D. Rossing, D. S. Hampton, U. J. Hansen, "Music From Oil Drums: The Acoustics of the Steel Pan," *PHYSICS TODAY*, March 1996, p. 24.
- T. R. Moore, "A Simple Design for an Electronic Speckle Pattern Interferometer," *Am. J. Phys.* **72**, 1380 (2004).
- B. Copeland, A. Morrison, T. D. Rossing, "Sound Radiation from Caribbean Steelpan," *J. Acoust. Soc. Am.* **117**, 375 (2005).
- A. Morrison, "Constructing and Using a Low Cost Speckle Pattern Interferometer for Analysis of Musical Instruments," *J. Acoust. Soc. Am.* **124**, 2510 (2008).

The online version of this Quick Study includes captioned active-intensity maps.