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The Hang musical instrument

My name is Jim Woodhouse. I am an emeritus professor of the Department of Engineering in the University of Cambridge. I did a first degree in mathematics, followed by a PhD on the acoustics of the violin. After working for an engineering consultancy firm on a variety of problems in structural vibration, I joined the University of Cambridge in 1985. My research interests all involve vibration, and musical instruments have continued to form a major part. I have published extensively in research journals in my field of expertise, many of them concerning the acoustics of instruments. I am familiar with the Hang and the handpan family of instruments, and their relation to the longer-established Caribbean steelpans.

I have been asked by the law firm Walder Wyss Ltd. to prepare an opinion on technical aspects of certain features of the Hang. I understand that this opinion will be used in proceedings between a number of handpan makers and dealers, on one hand, and PANArt hangmanufacturing Ltd., Felix Rohner, and Sabina Schärer, on the other hand, currently pending before the Commercial Court of the Canton of Bern.

<u>Scope</u>

I understand that the following design features are claimed by PANArt hangmanufacturing Ltd., Felix Rohner, and Sabina Schärer to constitute the essential features of the Hang:

1. the basic lenticular shape, consisting of two spherical segments;
2. a central dome ("Ding");
3. an opposing opening ("Gu");
4. the sound fields arranged in a circle on the upper spherical segment.

I have been asked to explain the technical aspects of these features and to assess whether their design is pre-determined by technical or other constraints required to produce an instrument with sound and playing characteristics associated with instruments in the Hang or handpan family.

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I should point out that there seems to be some unclarity as regards the second feature. The “Ding” generally describes the (whole) central note of a handpan. This central note consists of two parts: the main tone field (i.e., the annular-like region surrounding the central dimple), and the protruding dimple (“dome”). The dimple and the tone fields have different functions. Hence, it is unclear whether the central note or the dome shape in the centre of this note is claimed to be the relevant design feature. I will therefore address both.

About the Hang or handpan family of instruments

Handpans and the Hang are members of the **idiophone** family. Idiophones produce sound by striking the body of the instrument, and often the whole body vibrates (as in a bell). Steelpans, Hang, and other handpans are designed to isolate the vibrations within specific tonefields, in order to obtain **multiple separate notes** in one instrument, and to be able to tune the vibrations to achieve specific notes **with specific overtones**.

In the Hang and other handpans, these overtones are very specifically tuned, and a high degree of isolation of the notes is required and achieved to minimise note crosstalk: this (and the use of fingers rather than sticks) results in **a very mellow/soft sound which is characteristic of the Hang/handpan**. To achieve this the Hang/handpan needs many features in common with the steelpan (e.g. spherical curved shell), and some additional features (e.g. different choices of note spacing, the stiffening dimple in the centre of each tonefield).

The science of the handpan

First to establish the underpinning physics. Every object has vibration resonances (or “modes”) when it is struck. Usually, each mode involves the whole of the structure (i.e. of the idiophone). The first special thing about a steelpan or handpan is that certain of these **vibration modes are confined to small regions**, which the player perceives as the separate notes of the instrument. This feature is shared by rather few other instruments, but one example is the “musical saw”.

The second thing, in common with many other tuned percussion instruments (such as xylophone bars, carillon bells or tuned drums like tympani), is that each note does not simply involve a single mode, with its resonance frequency: there are multiple “overtones” which are also created when the note is hit. The steelpan- or **handpan-maker tunes three (or sometimes four) modes within each note region**, to achieve a pattern of resonance frequencies that are (at least approximately) part of a **harmonic series**. A harmonic series contains tones with frequencies that are integer multiples of the fundamental frequency. Such tones blend harmoniously. This combination of confined modes in harmonic relations is the essential thing that gives the “musical” tone to each note.

The physical mechanism of mode confinement in a pan involves the curvature of the body of the instrument. Each note has a very low curvature for most of the tonefield (to the casual observer it looks flat): I return later to the highly curved central dimples within the tonefields in handpans which has a special stabilising purpose. The low-curvature note is surrounded by metal that is everywhere curved: which is referred to as the internote region of the instrument shell. The change of curvature around the edges of the note region causes so-called total internal reflection of vibration, so that it (mostly) cannot escape the note region. (A similar phenomenon is the key to the behaviour of optical fibres, among many other systems.)

The required change of curvature could, in principle, be achieved by a spherical or ellipsoidal surface, or by other curved shapes that have curvature with the same sense (in/out) in all directions. A **flat plate or an object with flat facets like a pyramid or cube will not work** by this particular physical mechanism of mode confinement relevant to pans.

In order to be able to precisely and reproducibly tune the overtones, it is very advantageous for the tuner if the **curvature of the internote region is the same in all directions: i.e. the body of the instrument is made from a spherical shell segment**. Without this, the tuner would have to relearn for each note how to tune the overtones, depending on its position and orientation on the instrument. This use of a spherical shell segment is universal in Caribbean steelpans (which are the direct ancestors of handpans): it gives an **ideal “neutral canvas”** onto which to construct the notes.

A casual statement is sometimes made that the sound of a note is dependent only on the geometry of the note itself, and by implication not on the instrument shape, so that any instrument shape could be used. This statement ignores the fact that, without this surrounding stiff shell, the note itself would not exist because there would be no vibrational confinement. The casual statement and its implication are simply **not true**.

An equivalent scientific way to describe the confinement phenomenon is to say that the tonefield has a low **dynamic stiffness** compared to the high dynamic stiffness of the supporting shell. This so-called mechanical impedance change enables the mode confinement. It is well-known in engineering that curved sheets (known as shells) have high stiffness compared to the inherent material stiffness of the same material in flat or less-curved form. A familiar example is the use of corrugated sheet for roofing.

The vibrational modes confined within a note could still take a large number of different configurations (and so produce harsh or un-musical sounds). So, the handpan-maker tunes the first few modes to the desired harmonic frequency ratios by shaping the main curvature of the tonefield (tonefields are slightly convex), its outline and area, and the details of the curvature in the centre and at the periphery of the tonefield.

It is important for the long-term viability of the musical instrument that these carefully tuned frequencies remain unchanged despite the impacts a player imparts with their fingers. **The centre of the tonefield**, being far from the stiffened edges, **would be the least easy to control and most unstable part of the tonefield**. So, **the handpan-maker stiffens this central region** in order to stabilise the overtones of the note, by giving it a high curvature. **This is the mechanical function of the dimple in the centre of the note**. It is of secondary importance whether this dimple is concave (a dip) or convex (a dome). A dome (vs dip) is used for ergonomic reasons at the apex note: to enable it to be struck more easily in this apex position, given that the hand and fingers have a different type of trajectory and orientation at the apex of the instrument.

The dynamic stiffness of the spherical shell shape is also important because any vibrations escaping from the notes into the shell can excite resonances in the shell itself, creating “junk tones”. By ensuring that **the shell has very high dynamic stiffness (high and uniform curvature)**, these resonances in the shell itself are kept much higher in frequency than the note tones, so that they are unlikely to be excited and do not interfere with the musical sound. **This is required of both the top shell (containing the notes), and the bottom shell**. If the bottom shell were not curved, or were less curved, it could create junk tones.

There is a further reason for the top and bottom shells to be similar spherical segments (and so form a lens shape). This is the **static mechanical (structural) stiffening effect of the stiff lower spherical segment** when it is joined to the top shell. This combination of two spherical surfaces with opposite curvature renders the circular edge join of the instrument very stiff, and thus stabilises the structure of the playing surface and the whole instrument as it is handled, transported, and played. The technical reason for this stiffening effect is that the top shell on its own could deform in a so-called inextensional manner, but the two-sided closed shell cannot do so. Without this stiffening effect, the top playing surface could undergo the kind of structural distortions which are (more exaggeratedly) familiar to users of soft contact lenses when they are trying to pick up the lens. In a steelpan a somewhat similar edge-stiffening role is played by the cylindrical skirt of the pan, but that approach is not suitable for an instrument which is played on the lap.

Finally, I have described above mode-confinement within the tonefields: the containment of vibrational energy within the note. **This is never perfect confinement**: a small amount of vibration occurs outside the tonefield. Even if the tuner achieves ideal mechanical impedance change at and around the note boundary, so that little to no vibration escapes the note, there is always a so-called evanescent field of vibrational energy which exists (but gradually dies down with distance) outside the note boundary (which cannot be suppressed, irrespective of the skill of the maker). **Other notes must be kept away from or blocked from this leaking vibration**, or they could become excited and produce unwanted tones: this is called “crosstalk”.

The best way to do minimise crosstalk is to separate notes by a large amount of internote surface. This accounts for **the uniform distribution of notes in a circle** around the shell, with one note in the centre (see below). This is not an aesthetic choice, **it is a mechanical necessity to ensure good vibrational isolation** and so minimal crosstalk between notes. A circular arrangement of notes has been used in steelpans for decades, notably before the Hang.

Another way to reduce crosstalk is to ensure that notes which are adjacent to each other on the shell are not close in frequency: this frequency separation also reduces crosstalk. For this reason the maker typically places the rising notes of the musical scale alternately from one side to the other of the pan. But there is one note which is physically closest to all the other notes: the central apex note. So, the best choice for this note is the bottom-frequency note, the largest tonefield and the tonic of the scale: because it is **furthest in frequency** from any of the other notes. **Placing the largest note centrally is a means to minimise vibrational crosstalk**.

The **opening** on the lower shell creates a **Helmholtz resonance**, which imparts a deep base hum, and can be exploited to produce unusual sounds in certain specific ways to play the instrument. Such Helmholtz resonance would not occur without an opening.

The frequency of a Helmholtz resonator is determined by the internal volume, the area of the opening and some details of the shape around the opening. A neck-shape of the opening is important for the tuning of the Helmholtz resonance. Outward-facing necks are very uncommon for ergonomic reasons, because they create a fragile and unwieldy part of the instrument for transport etc., which can also get scratched and create a sharp edge causing injury. By contrast, inward-facing necks to Helmholtz resonators are nothing new and known from other instruments (e.g. in a tornavoz for guitars).

The central position of the opening further allows the player to influence the frequency of the Helmholtz resonance by opening and closing the legs while playing the instrument on the lap. The player thereby (artificially) reduces the size of the opening. Positioning the opening centrally on the lower shell further prevents the opening from being accidentally covered during play (e.g. by the player’s leg or support structures).

Furthermore, an opening is **required for tuning the instrument**. While the main tuning is usually done before the shells are joined, the tuning is slightly affected by the joining process, requiring that the notes are re-tuned after joining. Besides, all instruments need re-tuning after prolonged use. Ergonomically, positioning the opening in the centre makes it easiest to reach all the notes from within the instrument when tuning it; if the hole was substantially non-central, this would make it very difficult to reach the notes.

Conclusion

In view of the above, I find that all the features claimed to constitute the distinctive and defining features of the Hang are pre-determined by technical, ergonomic, and/or manufacturing constraints required to produce an instrument with sound and playing characteristics associated with instruments in the Hang or handpan family:

1. Lenticular shape, consisting of two spherical segments: The two spherical shell segments forming the lenticular shape are required in order to achieve high (and uniform) mechanical **stiffness**: both dynamic stiffness (for the production of musical sounds) and static stiffness (for stabilizing the mechanical structure of the instrument).
2. Central note with a dome: Placing the largest tone field (lowest note) centrally among other notes helps to **minimize crosstalk** and preserve the mellow and harmonious sound of this family of instruments. The dimples in every note, whether convex (dome) or concave (dip) serve to mechanically **stabilize the structure and vibrational modes of the note**. Making the dimple of the central tone field convex (instead of concave), is **ergonomically dictated** by the different trajectory and orientation of the hand at the apex of the instrument.
3. Opposing opening: Without the resonance hole there would be no **Helmholtz resonance** (low-tonal hum). An opening is also required for **tuning**. Access to both sides of the note is required after the two shells have been joined. Placing this opening centrally on the lower shell is **ergonomically the best position**. It also allows the player to influence the frequency of the Helmholtz resonance by opening and closing the legs while playing the instrument on the lap.
4. Circular arrangement of notes: A circular arrangement of the notes is the optimum way to space out the tonefields and maximise their separation. This is required to enable **vibrational isolation** of the tonefields and **minimise vibrational crosstalk** between the notes, which can produce unwanted harsh-sounding musical tones. Such circular arrangements were already well established in steelpans, long before the invention of the Hang.

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