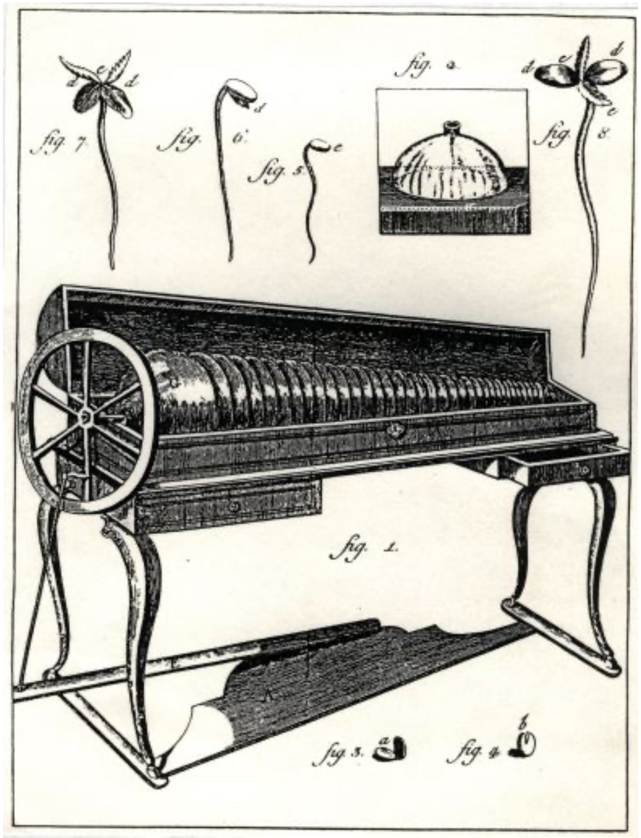
Musical Acoustics

Coursework



The Glass Harmonica

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Audio Technology

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1. Introduction

a. Properties

The glass harmonica is a collection of manufactured glass bowls, which overlap leaving only their rims visible, mounted on a rotating spindle, encased within varying types of apparatus which serve as a stable foundation and housing. The spindle where the glass bowls are mounted was originally rotated by a handle or a foot pedal connected by wire to a wheel, similar to early sewing machines.

The glass cups were to be played by moistened fingers; However, the encapsulation of the instrument could sometimes be seen to hold a shallow trough of water, eliminating the need for the musician to continually dip their fingers in water. While the instrument is highly customisable in nature, each bowl is made corresponding to a specific note, and was intended to mimic the piano in the way it was played and approached by the musician. It also was intended to represent the diatonic scale; the width was later being extended to four octaves up from the C below middle C.

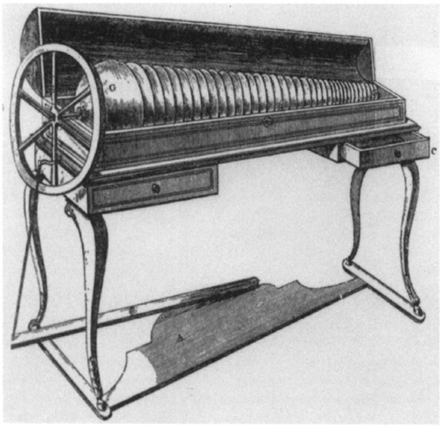

Figure 1; Early Drawing of the original "Glass Harmonica."

This is why many bowls within the glass harmonica are seen to be primed with different colours representing musical notes and points of reference for the operator. Its name the "Harmonica", derives from the Latin word "Harmonicus" which translates to tuneful or harmonious. This corresponds well with earlier writings and even some modern, passive observations in which they are called the singing bowls or cups.

b. Creation

The invention of the glass harmonica is most commonly attributed to Benjamin Franklin in the year 1761 (The Franklin Institute), this can't be disputed in the sense that he certainly was the first to create a device which could house and improve upon already existing glass music. It is told that Mr Franklin found inspiration during his time spent living in Paris and London. Here it was commonplace to find amateur performers in public and private settings playing gentle and alluring melodies on what would appear to be wine glasses filled with varying amounts of liquid. While the full history will be later investigated, Mr Franklin's tale reveals that he heard a fellow of the Royal Society, E.H Delaval playing upon musical glasses and immediately began work with a London glassmaker to improve the instrument. Upon completion of Franklins first glass harmonica, The Franklin Institute reports that he sent a letter to a Padre Giambatista Beccaria (a well-known Piarist scholar of the time) on July 13, 1762. He provides descriptions of his improvements and its angelic properties. Mr Franklin wrote:

> "The advantages of this instrument are that its tones are incomparably sweet beyond those of any other; that they can be swelled and softened at pleasure by stronger or weaker pressures on the fingers, and continued at any length, and that the instrument, being once well tuned, never again wants tuning."

c. Categorisation

To help place the glass harmonica figuratively, it can and is commonly referred to as a friction idiophone. This is the definition of the instrument laid out in the Hornbostel-Sachs system of musical instrument classifications. This system, is a further expansion on the earlier work of the acoustician Victor-Charles Mahillon, aims to organise musical instruments into relative groups, based on matters such as their physical characteristics and acoustic properties. The example discussed in this report is considered a friction vessel due to the nature of the musician to instrument interaction. Sachs states in his system that it is important to distinguish between "rubbing and scraping", as scraping a notched surface with a stick will result in audible beats, whereas the rubbing of a notched surface with a non-sound producing object such as moistened fingers, relies on the intensity of adhesion and friction to generate and sustain tones.

2. Research

a. Predecessors?

Glass music has been a tradition as far back as antiquity, although there exist claims that an Irish inventor by the name of Richard Pockrich popularised glass cups played by sticks and eventually by hand around 1741, naming the instrument the angelic organ.

His influence upon the western world's adoption and appreciation for the instrument of glass can't be refuted. Although it has to clarified that the practice of using different sized glasses, filled with a varying viscosity of fluids to create sound has been an area of investigation for at least 240 years pre-dating Mr Pockrich.

Source material for such antique knowledge is hard to verify with a lot of data being restricted to word of mouth or abstract paraphrasing. For purpose of reporting, one story tells that the principals previously discussed, where recognised, understood and practiced as early as 1300 A.D in Asia and the East. Some unverified sources date this even earlier. While maintaining origins of what would be ancient Mesopotamia and surrounding areas.

Figure 2; Abstract from "Theorica Musicae", 1492.

Some of the earliest workings that can be found in regard to the investigation of resonance, using the materials of glass and fluids to create sound. Include that of Gaffurius, Franchinus – (Theorica Musicae, 1492), where a woodcut appears to depict two scientists conducting a Pythagorean experiment involving varied glasses and bells, struck by rods.

It is further purported that in the works of G.P. Hasdorfer, (Deliciae Physicomathematicae, 1677), he writes;

> "There is an account of an experiment with four glasses, filled with brandy, wine, water and salt water or oil. The diverse sounds produced by the contrasting content of the glasses were thought not only to correspond to the emotions aroused by the four "humours" of the human body, but even to have the power of alleviating or curing such disorders as a thickness of the blood."

b. Celebrity Status

The glass harmonica began gathering recognition for its bewildering yet fascinating tones and in turn grew in popularity throughout Europe and the Americas for the next 40 years. Masters of the craft were few and far between as access to such elegant equipment would not be commonplace, especially if the reader considers the time period in question. This meant that those who could manipulate the enigmas that were the singing bowls, namely Marianne Davies (1744-1792) and Marianne Kirchgessner (1769-1808) found themselves highly sought after for their peculiar abilities. It is an interesting parallel to draw but only theoretical, in recognition of the prominent players of the instrument being ladies. They may have taken motivation from seeing this musical instrument that appeared approachable as its design and functioning resembled that of the early sewing machine. Once they understood the concept, they were far more equipped to intuit the systems rhythms and apply the necessary delicate touch involved in attaining the purest tones.

The instrument became so popular that the likes of Mozart and Beethoven composed works which introduced glass music. Mozart created several pieces such as Fantasia in F Minor, K.608 or the Adagio and Rondo in C Minor, K.617. Other notable admirers of glass music and its effect on human consciousness include that of Schiller and Goethe. A Glass harmonica factory was later founded in Bohemia, an area renowned for its tradition in spectacular glass and ceramic skills.

c. Notable Mentions

The aforementioned Marianne Davies, an English musician and sister of the classical soprano Cecilia Davies. Was one of if not, the first musician who played the glass harmonica designed by Franklin in public. Reportedly touring London and Dublin to showcase her talents. Eventually the sisters became acquainted with the writers of compositions intended for the instrument such as Mozart and Beethoven, who applauded and admired their particular skillset.

It's worthwhile mentioning the three-act opera composed by Richard Strauss, "Die Frau ohne Schatten." Thought be created sometime between 1911 and 1917, by it is a tale of an emperor and empress set in a mythical land. The empress is half human, she was initially captured by the emperor in the form of a gazelle and after she changed form, he married her.

Figure 3; Artwork associated with the opera, The woman without a shadow.

Her lack of a shadow symbolises her inability to bear children, alongside being a spiritual creature in a human world. After premiering at the Vienna State Opera in 1919, it received mixed reviews from critics as Hofmannsthal's libretto was considered heavily symbolic. Fast forward to today, it is now a standard part of the operatic repertoire. Still inclusive of the originally composed glass harmonica section within the 164-piece orchestra.

Another notable professional would be Bruno Hoffman, who contributed more than anyone to resurgence of glass instruments in the western world throughout the 20th century. Born in Stuttgart, 1913, many of his vinyl presses still remain today where curious minds can appreciate the recordings of a select few professional glass musicians.

d. Resonance

All physical materials have a naturally occurring frequency at which they vibrate, this is called its "Resonant Frequency", and can be thought of as the idle frequency of the item in question. This frequency is one which the system will oscillate at without external influence. The theory of resonance tells us that, its effects can be detected when driving or dampening waves are applied to a naturally resonating system once they begin oscillating at a similar frequency, there will be a perceived increase in the amplitude of that resonant frequency.

There is a formula that can be applied in order to calculate the resonant frequency of a single continuous wave.

$$V = \lambda f$$

This shows us that the wave velocity (V) is equal to the distance of the wavelength (λ) multiplied by the resonance frequency (f).

If the formula is manipulated it can be seen as the resonance frequency is equal to wave velocity divided by the distance of the wavelength.

$$f = \frac{v}{\lambda}$$

Further applications include using a set of formulas to discover multiple resonance f frequencies for different waves moving at the same time.

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{2L}$$

e. Application to the physical

If this concept is applied to the case of the wine glass or the glass harmonica, the calculations become increasingly complex; However, this can be simplified somewhat if the reader considers only the additional variables at play, as appose to the mathematical principals needed to decode this riddle.

$$\left(\frac{f_0}{f_d}\right)^2 \approx 1 + \frac{\beta \rho_l R}{5 \rho_g a}\left(1 - \frac{d}{H^*}\right)^4$$

f_0 = frequency of empty glass
f_d = frequency of partially filled glass (Hz)
β = a constant
ρ_l = density of liquid
ρ_g = density of glass
R = radius of water
a = glass thickness
d = distance from top of glass top water
H^* = effective height of glass

Figure 4; Formula for calculating the resonant frequency of a cup filled with liquid

The resonant frequency naturally occurring within the glass plays, unheard and uninterrupted. Once a moistened finger contacts the glass and begins to create circular motion around the rim, this energy creates an oscillating wave which is passed on to the glass molecules who begin to resonate and create fluctuations in the air molecules whose frequencies correspond directly to the resonating frequency. It is these fluctuations in the air molecules, or waves which the glass and the operator co-create that can be sensed audibly.

If the reader were to refer back to (Figure 4), the added mass and molecules of the water which are now incorporated within the glass reduce the energy of said resonating wave. In turn reducing the frequency of that wave, this can be perceived as an alteration in pitch, which is manipulated by altering the volume and viscosity of liquid contained within the glass.

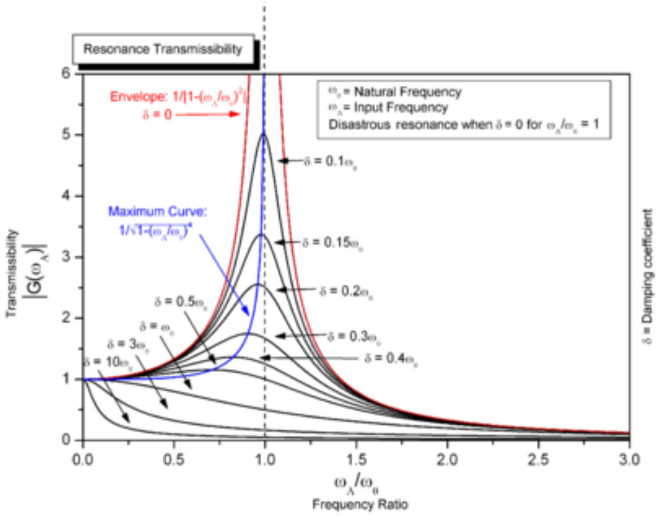

Figure 5; Spectrum of a simple harmonic resonator.

Most people could visualise and understand the opera singer, shattering glass with nothing but her voice. This vision depicts clearly the previously explained phenomenon of resonance and its effects on the extreme end, where the energy imparted upon the glass at its particular resonant frequency creates oscillations that exceed the structures resistance. It would be near impossible to achieve this shattering of glass with a wet finger on a glass bowl.

However, an addition visual example of the effects of resonance and how its variables can change depending on environment and the system involved. Include that of the meticulous planning or lack thereof seen within in the building of modern-day bridges. It is well documented that resonance has been shown to apply to large scale physical structures, (Tacoma Bridge, July 1st, 1940 – November 7th, 1940.)

In the case of the Tacoma Bridge, wind speeds were travelling across the system, creating ripples or waves that are pushing against an otherwise stationary structure. Once those waves begin to oscillate at a similar frequency to the systems natural resonant frequency, resulting in amplification of said waves. Having the structure loaded beyond capacity, by something like a parade or heavy traffic with the added effects of high-speed crosswinds would most likely result in detrimental system failure due to amplified resonance creating unstable oscillations within the system. This can be seen in modern day bridges where there are capacity limits, weight limits and often strict rules in place relating to closure of said bridges in the event of high-speed winds.

8. Further Reading

a. Mesmerising

Glass bowls and glass cups began to gain popularity amongst spiritualists and hypnotists after the infamous Franz Mesmer (1734-1815), began to incorporate them into his hypnosis routine. Here he claimed to cure ailments and illnesses by manipulating “the ether” and transmuting “animal magnetism” from inanimate objects into healing energies which yielded real world responses.

It’s relative to recognise Mr Mesmer was quickly regarded as a charlatan in his day due his reference of non-physical phenomenon, which could not be verified by the method testing of the time. All said considered Mr Mesmer is still considered one of the founders of hypnotism. Similar to guided meditations offered at the time of writing, it is believed it is not the singing glass nor other elaborate contraptions that solely placed people into a trance. Instead, it was Mr Mesmer’s actions and speech alongside other audible, visual, and olfactory cues which when combined could induce certain mental states in individuals.

While incredibly difficult to verify subjective experience, it is important to mention these stories as we have little evidence to fully understand the reasoning behind glass music’s disappearance. The collection of previous tales all summarize the same instrument as supposedly being cursed, angelic, and sweet simultaneously. How could one instrument encompass such diverse emotional responses.

b. Fall From Grace

Even though the glass harmonica and glass music in its totality experienced a sharp rise in popularity during the previous times, this was relatively short lived as before it could be adopted by all composers and orchestras it was ostracised by many under the grounds it was a haunted instrument. Which would eventually cause the operator to descend into madness, or ill health.

The famed Marianne Kirchgessner (1769-1808) was blinded by an eye disease, caused by smallpox when she was four years old. Despite this she managed to attain the recognition from many reputable composers in Vienna, at the time due to her artistic capabilities, and exceptional skill on the glass harmonica. Upon her sudden death many romanticists of the time, placed the blame upon the repeated use of the famed instrument, although it is reported she died of a fever and lung inflammation.

c. Human Hearing

This may offer some insight into the diverse response to this instrument and the subjective reaction it can initiate within the listener. The frequency range of the bowls contained in the glass harmonica fall between which is 1 kHz- 4 kHz. This range has been studied extensively as it represents a spectrum of frequencies the human ear is particularly sensitive to.

Humans have difficulty locating frequencies in this range within space, due to the resonance effect. Frequencies around from 1 kHz - 4 kHz are amplified in the middle ear canal and can range from being perceived as 10-20dB louder than other frequencies. This would have definitely contributed to the mystical properties' listeners heard and have attempted to describe.

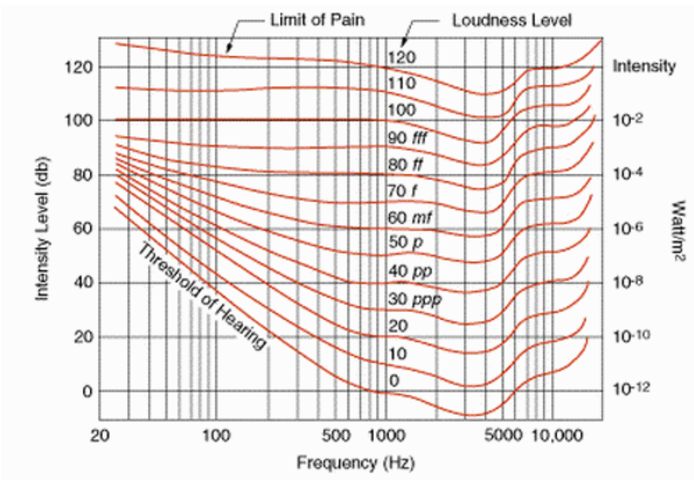

Figure 6; Limits of human hearing shown on an equal-loudness contour plot

If we consider Figure 6, this plot shows that with a tone of around 4 kHz, it needs very little energy to be perceived when compared with another frequency. On the opposite end of the scale, it can be deduced that frequencies below 100 Hz and above 19 kHz need a far greater amount of energy if they are intended to be perceived by human listeners. The plot leaves more questions than answers, as this is the purely the product of evolution. Many have assumed that this plot was formed through neural pathways associated with speech and translation. However, the characteristic frequency of human speech is located around 80 – 260 Hz. In today's age we know that the middle ear resonates at approximately 1230 Hz (Analysis of Resonant Frequency of the Middle Ear, Frade C, May 2000).

9. Conclusion

Still to this day it remains vastly entertaining to imagine the environment of those people experiencing such phenomena for the first time. While having little to no theoretical explanation you don't have wander far to make assumptions on what they would feel or have believed about this instrument. There bears some truth in the rumours that this instrument would gift the operator ill health, as glass of that time period areas was comprised of lead, as was the paint which was used to illuminate the rims of the glass bowls. Thus, continual lead residue from both sources combined with poor sanitation conditions, it is easy to make that correlation. Although we do not possess raw data to confirm or disprove. It can only be assumed what the true nature of glass instruments' disappearance can be attributed to. Additional factors such as lack of means to amplify the glass harmonica beyond a certain limit, meant that while contained within large orchestras, the pure tones of the Glass harmonica would be reduced to mumbles.

10. Modern Video Samples

The opera "Lucia di Lammermoor" features a rare glass harmonica performance by William Zietler.

https://www.youtube.com/watch?v=eEKlRUvk9zc

Adagio, for the Glass harmonica, K 356, Wolfgang Amadeus Mozart (1756-1791), Performed by Dennis James

https://www.youtube.com/watch?v=QkTUL7DjTow

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http://www.operavivra.com/blog/glass-harmonicas-opera/ (Lucia Di Lammermoor madness scene)

https://www.alasdairmalloy.com/glass-harmonica/
(Prominent Glass harmonica player of recent times)

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Éléments d'acoustique musicale & instrumental

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Appendices

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https://www.glassarmonica.com/media/resources/dipl_93.pdf
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