Water Depth and Frequency of a Jingdezhen Bowl

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Abstract

The relationship between the resonant frequency and water level in a Jingdezhen porcelain bowl was investigated for the first two modes of resonance. The range of water levels studied was between 0 and 39 mm below the rim. It was found that the non-cylindrical bowl can be modeled by an equation originally derived for cylindrical wine glasses for both the first and second resonance modes.

Keywords: Porcelain bowl, Jingdezhen, resonance, frequency, water depth

I. INTRODUCTION

Jingdezhen has long been the capital of porcelain production in China. Though Jingdezhen porcelain has a history dating back to 6th century AD, international trade and mass production began during the Ming dynasty (1368 – 1644 AD)[1]. One important characteristic of Jingdezhen porcelain bowls, figure 1, is their thin walls, allowing for lightness and delicacy. Another characteristic is the blue glaze and painted designs. They are beautiful but an often-overlooked selling point of Jingdezhen porcelain bowls is that they are especially designed to make a beautiful ringing sound when tapped. This is part of the traditional pottery techniques passed down through the generations and still practiced today.

Figure 1. The bowl used in this experiment

The frequency of the sound can be varied by changing the water level inside the bowl. Since the relationship between water level and frequency has been studied for wine glasses and metal Tibetan bowls, it would be interesting to see how this relationship can be described for a Jingdezhen porcelain bowl, since it is non-cylindrical and made of a different material. This study may give insight into the limits of applicability of the equation derived for wine glasses, which will be tested as a model for the ringing of the porcelain bowl.

A.P. French[2] conducted a study in 1982 to derive and test the equation that relates the fundamental frequency and water level for a cylindrical wine glass, shown below,

$$\left(\frac{f_0}{f_d}\right)^2 \approx 1 + \left(\frac{\beta l R}{5ga}\right)\left(1 - \frac{d}{H}\right)^4 \qquad (1)$$

where f_0 is the frequency of the empty glass, f_d is the frequency of the partially filled glass, β is a constant dependent on Young's Modulus, l represents the density of the liquid, R is radius of the container, and g is the density of the glass, H is the height of the glass, a is glass thickness, and d represents the distance from the top of the glass to the top of the water.

A study by Terwagne and Bush[3] showed that the equation French derived for cylindrical wine glasses can be applied to Tibetan singing bowls.

Figure 2. Tibetan singing bowls, similar to the one tested by Terwagne and Bush.[3]

Tibetan bowls are mostly made of a bronze alloy including metals such as copper, zinc, tin, gold, nickel, iron, and silver. When striking or rubbing the rim with a mallet, the bowl vibrates, causing a sound to be produced.[3]

Terwagne and Bush showed that a graph of $\left(\frac{f_0}{f_d}\right)^2$ against $\left(1-\frac{d}{H}\right)^4$, shown in figure 3, produced a linear fit with a y-intercept of 1, matching equation 1 which was derived for cylindrical wine glasses.

This suggests that the equation derived for cylindrical wine glasses also applies to metal bowls that slightly deviate from a cylindrical shape. This then raises the possibility that the equation applies to other non-cylindrical resonating containers, made from other materials, such as the porcelain bowl used in this study.

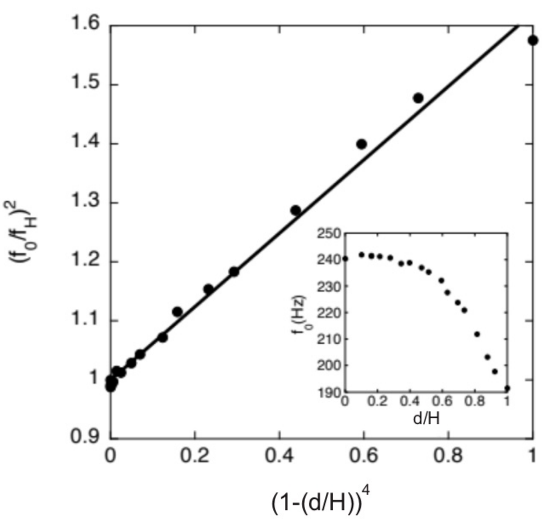

Figure 3. Graph of $\left(1-\frac{d}{H}\right)^4$ and $\left(\frac{f_0}{f_d}\right)^2$ for a Tibetan bowl.[3]

The ringing sound of Jingdezhen porcelain bowls have not been extensively studied before. Here, the relationship between frequency and water level in the bowl will be investigated and compared to the theoretical model for a cylindrical wine glass, as derived by French.

II. METHODS

The bowl used in this study (figure 1) had a height of 47.3 ± 0.05 mm. The thickness of the walls in the middle of the bowl was measured using a Vernier caliper to be 2.00 ± 0.05 mm. Though the thickness of the walls of the bowl was almost uniform in the middle, it was thicker at the base and grew thinner near the rim. The density of the ceramic material was calculated, from the measured mass and volume of the bowl, as 1.39 ± 0.02 g/ml. Room temperature was 26 ± 1.5 ˚C. The temperature of the water in the bowl at the start was 30.0 ± 0.5 ˚C, and fell to 24.5 ± 0.5 ˚C by the end of testing due to a drop in temperature of the room. The maximum volume of water in the bowl was measured to be 360 ± 1 ml.

A Vernier microphone was connected to LoggerPro on a computer, with sample rate set at 100,000 samples per second for 0.3 seconds. A Vernier caliper was used to measure the height of water in the bowl and the inner height of the bowl. There were six variations of the water level tested between 0 (empty bowl) and 39 $\pm$ 0.05 mm, with four trials taken for each variation. The bowl was gently tapped on its rim with a wooden rod and the sound recorded and the peak frequencies for the first two modes of resonance were recorded, as shown in figure 4.

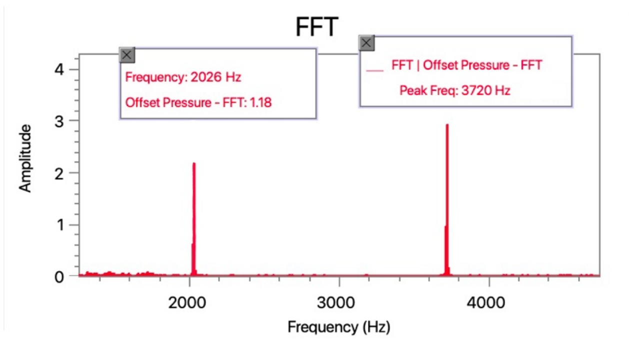

Figure 4. Sample FFT graph for water height 6.5 mm, trial 3, showing frequencies of 2026 Hz and 3720 Hz for the first two resonance modes.

III. RESULTS AND DISCUSSION

As shown in figure 5, $\left(1-\frac{d}{H}\right)^4$ was graphed against $\left(\frac{f_0}{f_d}\right)^2$, following French's model. This was done for both the first and second modes of resonance. It was found that there was a linear relationship between $\left(1-\frac{d}{H}\right)^4$ and $\left(\frac{f_0}{f_d}\right)^2$ for both modes of resonance, showing that a non-cylindrical Jingdezhen porcelain bowl follows the model derived for a cylindrical wine glass.

From figure 5, the equations that can be derived for the fundamental and second harmonic frequencies are shown below, with equations 2 and 3 for the first and second modes of resonance, respectively.

$$\left(\frac{f_0}{f_d}\right)^2 \approx 1 \pm 0.01 + 1.23 \pm 0.06 * \left(1-\frac{d}{H}\right)^4 \quad (2)$$

$$\left(\frac{f_0}{f_d}\right)^2 \approx 0.99 \pm 0.02 + 1.08 \pm 0.06 * \left(1-\frac{d}{H}\right)^4 \quad (3)$$

The y-intercepts for both the first and second modes of resonance are close to 1, which matches the predicted value within uncertainty. The slopes depend on the constants shown in Equation 1.

For the empty Jingdezhen porcelain bowl, the first and second modes of resonance had a peak frequency at about 2027 Hz and 3726 Hz respectively. For the empty Tibetan bowls tested by Terwagne and Bush, the first and second modes of resonance had a peak frequency at about 431 Hz and 1240 Hz.[3] The ratio between the first and second modes of resonance for the empty porcelain bowl was found to be 0.54, and 0.35 for the Tibetan bowl. The ratio between the first and second resonant frequencies for the porcelain bowl is greater compared to the ratio for the Tibetan bowls, possibly due to differences in the shape of the bowls. The Tibetan bowl was close to being cylindrical, whereas the porcelain bowl used here has a radius that increases from the base to the rim.

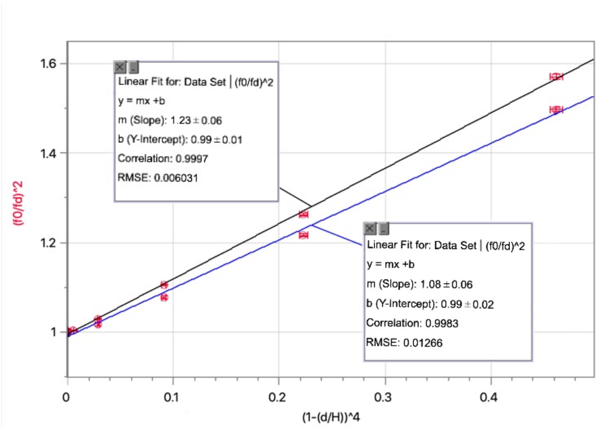

Figure 5. Graph of $\left(1-\frac{d}{H}\right)^4$ and $\left(\frac{f_0}{f_d}\right)^2$ for the first (blue) and second (black) modes of resonance.

Further research is recommended to determine if cylindrical containers made of ceramics or other materials follow French's model. A theoretical model for a cone with uniform wall thickness could also be derived and tested for cones made of porcelain or other materials.

IV. CONCLUSION

It was found that the equation derived for cylindrical wine glasses[3] can be applied to a non-cylindrical Jingdezhen porcelain bowl. The graph of $\left(1-\frac{d}{H}\right)^4$ against $\left(\frac{f_0}{f_d}\right)^2$ was linear for both modes of resonance, with slopes of 1.23 ± 0.06 and 1.08 ± 0.06 respectively. For the empty Jingdezhen porcelain bowl, the ratio between the first and second modes of resonance was 0.54, which is higher than the ratio for an empty Tibetan bowl, calculated as 0.35. This is possibly due to the difference in the shapes of the bowls.

V. REFERENCES

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