THE ETIOLOGY OF CHATTER IN THE HIMALAYAN SINGING BOWL

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ABSTRACT

The Himalayan singing bowl is a nearly symmetric metal bowl that produces a musical sound by rotating a wooden stick around the outside rim. The wooden stick, referred to as a *puja*, excites vibrations through a stick-slip mechanism. The amplitude of vibration is related to the applied force and velocity of the puja as it moves around the bowl. Typically the (2,0) mode dominates the motion, resulting in narrow-band oscillation at a frequency determined by the size of the bowl. However, as the angular velocity of the puja increases and/or the force of the puja on the bowl decreases, an audible chatter will often occur. The goal of the work reported here is to determine the origin of this chatter. Initial results indicate that the puja does not lie directly on a node of the radiating deflection shape. Therefore, it appears that as the amplitude of the radiating mode is increased the puja can lose contact with the bowl resulting in a chattering sound.

1. INTRODUCTION

The Himalayan singing bowl is an idiophone that originated around 500 B.C.E. in the Tibetan mountain region. This instrument was classically used for meditation and religious purposes, but today it is also used for contemporary music making and personal enjoyment. The nearly symmetric bowls can range from approximately 10 to 30 centimeters in diameter and are traditionally made of several metals, including: tin, mercury, copper, gold, silver, lead, and iron. The instrument is played by rotating the *puja*, typically a wooden stick covered with felt or leather, around the outer rim of the bowl.[1]

This instrument is known to produce its signature ringing sound from a complex stick-slip mechanism, which is assumed to be similar to the process of using ones finger to make a wine glass sing.[2] While this stick-slip motion has been extensively studied in other instruments, to our knowledge, there have been few attempts to model the singing bowl and even fewer attempts to experimentally investigate the instrument. In the work reported here, we experimentally investigate a well known characteristic of the singing bowl, which we refer to as chatter. This phenomenon can be described as the rapid ”knocking” of the puja on the bowl as it rotates around the bowl.

2. THEORY

To our knowledge the work reported by Inacio et al. represents the only attempt to model the singing bowl. In this work, the rim motion of the singing bowl was modeled as a ring.[3] The results of this modeling effort predicted many of the notable characteristics of the singing bowl, including the ratio of the frequencies of the bowl resonances. Furthermore, acoustic measurements indicated that the radiating deflection shape is dominated by the (2,0) mode and that the deflection shape rotates around the bowl with the puja. The model proposed by Inacio et al. also predicted that as the angular velocity of the puja increases and/or the force of the puja on the bowl decreases chatter will occur.

While these investigations provided insight into the physics involved in the motion of the singing bowl and confirmed some of the predictions from the model, many questions remain unanswered. It was proposed that the puja always lies near the node of the rotating deflection shape, but the exact location was not determined and it is not clear why the puja does not lie directly on the node. Additionally, the model used a simplified representation of stick-slip motion that has yet to be experimentally examined. In the work reported here, we experimentally confirm that the deflection shape primarily consists of the (2,0) modal structure that rotates with the puja. We also investigate the stick-slip motion of the puja and confirm that the puja does not lie at a point of minimum displacement on the bowl.

3. EXPERIMENTS

The singing bowl under investigation has a diameter of approximately 123 mm, a height of approximately 72.5 mm, and a thickness of approximately 3.72 mm. The first resonant frequency occurs at 620.7±0.3 Hz.

To confirm that the deflection shape does indeed rotate around the bowl with a (2,0) modal structure, the vibrations of the bowl during play were studied optically using high-speed electronic speckle pattern interferometry (HSESPI).[4] The bowl was mounted on a stationary platform and the puja was rotated around the bowl by hand. The frame rate of the camera was 9.9 kHz. To view the relative displacement of the bowl as the puja rotated around it, each frame was subtracted from a frame captured at a point of minimum deflection. These images resemble a contour map where black lines represent contours of equal displacement. The interferrograms shown in Fig. 1 verify that the deflection shape resembles the (2,0) mode shape of a ring and that the position of the node travels around the bowl in near proximity to the puja.

The resonance frequencies of the bowl were determined by striking the stationary bowl with the puja and recording the audio signal with a microphone. We identified the frequency components with significant power from a power spectrum similar to the one shown in Fig. 2.

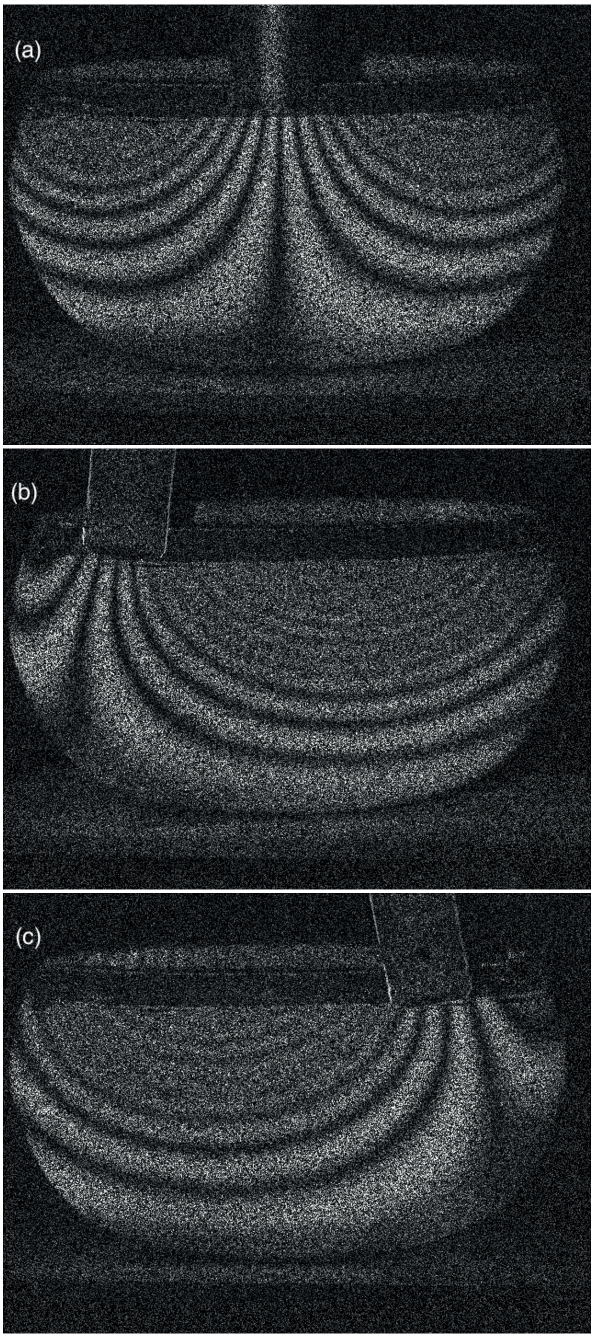

Figure 1: HSESPI images of the singing bowl during normal play (a) with the puja centered in the camera frame; (b) with the puja to the left of center; (c) with the puja to the right of center.

This power spectrum shows four clearly identifiable resonances, at approximately 621 Hz, 1735 Hz, 3144 Hz, and 4770 The ratio between the first two resonances can be predicted by modeling the bowl as a ring, with only approximately 1% difference between predicted and experimental ratios. The model becomes less accurate with the higher resonances, with the difference between the measured and predicted frequencies increasing to approximately 7% for the third resonance and approximately 14% for the fourth.

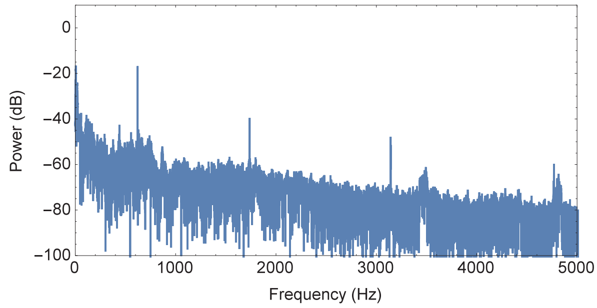

Figure 2: Power spectrum of the sound produced when a stationary singing bowl is struck with the puja.

The bowl was then mounted on a platform rotated by a variable speed motor. A wooden puja was mounted next to the bowl and touched the outer rim as the bowl rotated. The bowl revolved at two different speeds: first at 0.4 revolutions per second and then at 1.1 revolutions per second. While rotating at a slower speed a pure ringing was heard while there was a clear audible chatter when rotating at a faster speed. The audio signals for both speeds are shown in Fig.3.

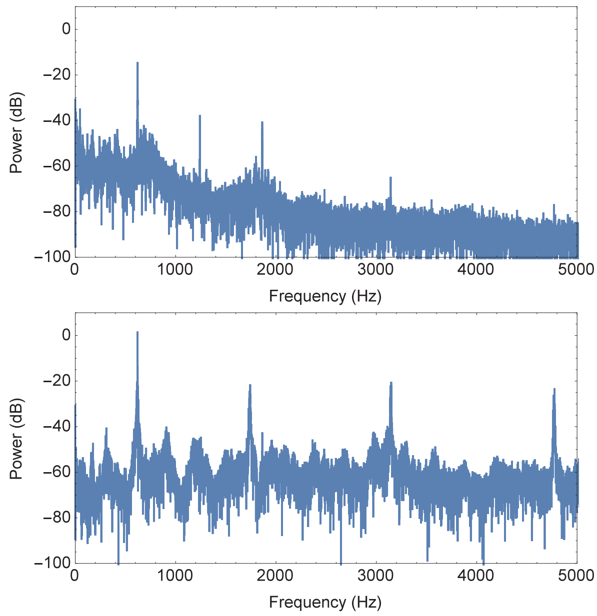

Figure 3: Power spectrum of the sound produced by the singing bowl as it is being played: (a) at 0.4 bowl revolutions per second, with no audible chatter, and (b) at 1.1 bowl revolutions per second, with a distinct audible chatter.

When no chatter is audible, the dominant frequency component appears at the first resonance frequency. Some harmonics of this frequency are evident in the spectrum, however, these are a product of the non-sinusoidal deflection shape at large amplitudes and do not represent resonances of the bowl. When chatter is heard, the higher resonances of the bowl appear in the power spectrum. This indicates that the bowl is ringing freely, and therefore, the contact between the puja and the bowl during chatter is similar to the contact made when striking the bowl.

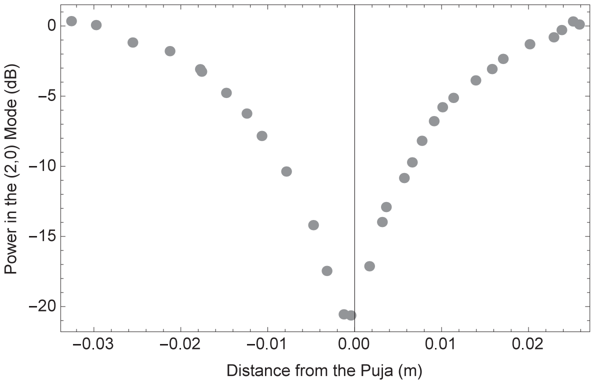

Figure 4: Power in the first resonance frequency recorded by the LDV vs. distance from the puja. Positive distance is in the direction of the bowl's rotation (clockwise). The zero position on the x-axis represents the point of contact.

To determine the position of the puja with respect to the position of the node of the (2,0) mode, which is the point of minimum displacement on the bowl, we measured the displacement of the bowl using a laser doppler vibrometer (LDV). We directed a LDV at the inner rim of the bowl and measured several points near the point of where puja contacted the bowl. A camera recorded a digital image of the puja and the point where the laser was incident on the bowl. From these images the distance from the puja to the point of measurement was calculated.

Figure 4 is a plot of the power in the displacement at the first resonance frequency as a function of position on the bowl. This plot indicates that the position of the node lies within 1.0 $\pm$0.5mm of the where the puja contacts the bowl. In this plot, the puja is ahead of the node in the direction of rotation.

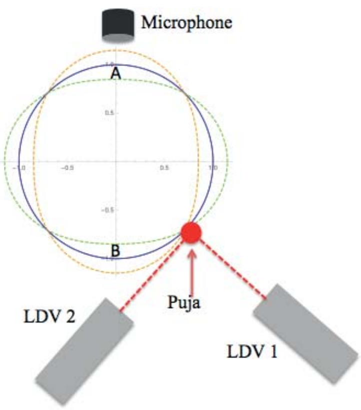

Figure 5: Experimental arrangement for determining the position of the node relative to the puja.

To confirm the position of the node with respect to the point of contact with the puja, we measured the phase difference between the motion of the bowl at one antinode and the puja. In the experimental arrangement shown in Fig. 5, one LDV was directed normal to the puja in the radial direction of the bowl and a second LDV was directed normal to the puja in the tangential direction. A microphone was placed near an antinode on the bowl, labeled as point A. By comparing the radial displacement of the puja to the displacement of the bowl, we were able to measure the relative phase between the puja and the bowl at the antinode. Measurements were made at speeds before and after chatter occurs, with the bowl rotating clockwise and counterclockwise. The tangential displacement of the puja was also studied to gain insight into the stick-slip motion.

4. ANALYSIS

In the final experiment described above, the microphone was placed close to the antinode at point A in Fig. 5. This motion is in phase with the oscillations of the antinode at point B. Figure 6 is a plot of the relative radial phase of the puja when the bowl is rotated at a speed of approximately 0.35 revolutions per second. Measurements when the bowl was rotated clockwise and counter-clockwise are shown. The sinusoidal pattern is attributable to a slight asymmetry in the mounting of the bowl and the pattern repeats four times per revolution of the bowl. It can be determined from Fig. 6 that the relative phase of the puja with respect to the displacement at the antinodes when the bowl is rotating clockwise is π out of phase with the relative phase when the bowl is rotating counter-clockwise.

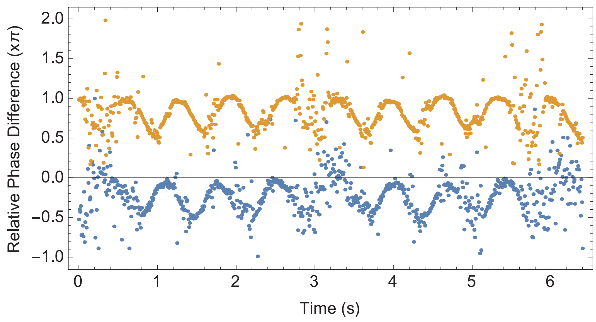

Figure 6: The relative phase of the puja in the radial direction when the bowl is rotating counter-clockwise (orange) and clockwise (blue). The bowl was rotating at 0.35 revolutions per second and periodic chattering occurred.

The radial motion of the puja is in phase with the antinode at point B when the bowl is rotating clockwise and out of phase when the bowl is rotating counter-clockwise. This indicates that the puja leads the node in the direction of rotation. Figure 7 is a schematic showing where the puja contacts the bowl with respect to the node and direction of rotation.

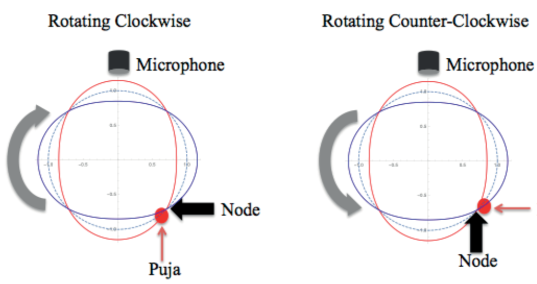

Figure 7: The location of the node relative to the contact point of the puja for clockwise and counter-clockwise rotation.

The second LDV was directed normal to the puja in the tangential direction to measure the stick-slip motion. A graph of typical tangential displacement is shown in Fig. 8. The results of this experiment suggest that a simple stick-slip mechanism can be used to model the tangential motion of the puja. However, there is clearly a more complicated motion than is normally assumed. Further investigations of the tangential motion are needed to better understand this process.

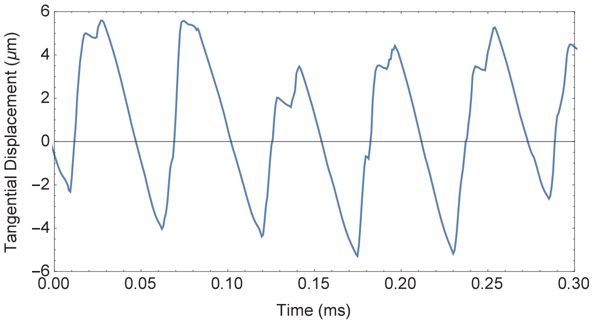

Figure 8: The tangential displacement of the puja when the bowl is rotating counter-clockwise at approximately 0.25 revolutions per second.

5. CONCLUSIONS

In the work reported here, we experimentally investigated the motion of the singing bowl and confirmed some of the predictions made in Ref. 3. When the singing bowl is played, it has a deflection shape that is dominated by the (2,0) mode, and the deflection shape rotates around the bowl with the puja. The puja forces a point of minimum displacement on the bowl, which lies in the vicinity of the contact point of the puja. From the results of the experiments described here, it appears that the point of contact of the puja is not at the node of the deflection shape, but rather the puja leads the node in the direction of rotation. Therefore, as the angular velocity of the puja increases, the amplitude of the radial displacement of the rim of the bowl increases, forcing the puja to briefly lose contact with the bowl and produce chatter.

6. REFERENCES

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