The Effects of a Resonator Tube on the Timbre and Directivity of Sound Radiated from a Vibraphone Bar

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ABSTRACT

A common method of amplifying the sound produced by a bar percussion instrument is to place each bar directly above a resonator tube tuned to one quarter wavelength of the bar's fundamental frequency. On a vibraphone, the effect of the resonator can be modulated with a rotating circular fin at the top of the tube. This research explores the changes in timbre and directivity produced when a resonator tube is placed under an aluminum vibraphone bar and the fin is turned to different angles of rotation.

1. INTRODUCTION

The characteristic sound of a vibraphone depends on the vibrato achieved when a set of motor-driven disks opens and closes the quarter-wave resonator tubes suspended under the bars. The tubes serve to amplify the fundamental frequencies of the bars. When the aperture of the tubes is modulated by the revolving fins, the main effect is a fluctuation in the amplitude of the sound radiated at that frequency. There is also a slight variation in pitch as the resonance frequency of the tube changes with the size of the opening [1].

The addition of a resonator tube also has the effect of changing the directivity of the sound radiated from the bar. The top and bottom of an unbaffled, free-free bar vibrate out of phase and thus radiate as a dipole. The resonator tube causes the air between its opening and the bar to radiate more efficiently as a monopole source [1]. When the tube is opened and closed with the rotating fin, the directivity of the fundamental frequency as well as the overtones can be expected to vary between these two patterns. This paper describes the methods used to observe these changes and the results of the observations.

2. THE BAR AND TUBE

The bar used in this experiment is an aluminum vibraphone bar tuned to Eb6, approximately 628 Hz. It has a length of 216 mm, width of 36 mm, and height of 9.5 mm at the ends. The height at the center is 4.5 mm due to a cylindrical cut of radius 130 mm in the underside of the bar. The bar is excited by a medium-hard, cord-wound vibraphone mallet wielded by a mechanical striker. The striker shown in figure 1 is designed to imitate the arm and wrist action of a percussionist. By cocking the arm back and releasing it from a prescibed height, it can be made to deliver a single, repeatable strike to the bar. A series of measurements of the initial velocity imparted to the bar by the striker shows that the variance of the velocity of each strike is less than 1% of the mean.

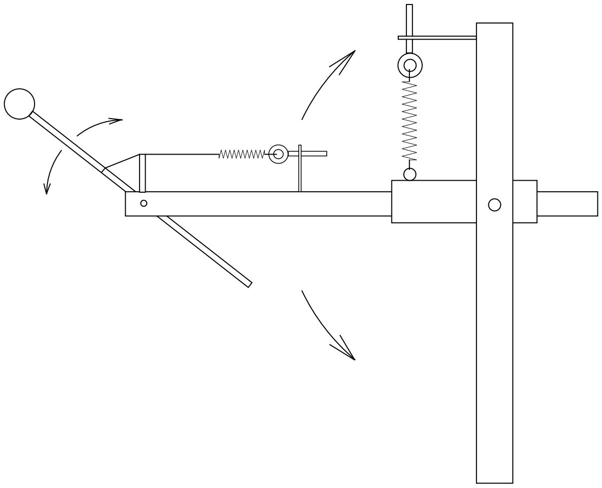

Figure 1: Mechanical Striker

The resonator is an aluminum tube, closed at one end and open at the other. Its radius is 2.5 cm, and its length is 12.8 cm. Using the end correction for an unflanged tube, $0.61\,r$, the effective length of the resonating air column is determined to be 14.3 cm. A metal fin with a radius of 2 cm is supported inside the tube near the top so that it can be rotated about a horizontal axis perpendicular to the length of the bar. The tube and fin are placed below the center of the bar so that the top of the tube is 2.5 cm below the top of the arch cut in the bar.

3. THE DIRECTIVITY MEASUREMENT

The apparatus is placed in an anechoic chamber, and two B&K condenser microphones are arranged in the soundfield. One is kept one centimeter below one end of the bar and is used as a reference. The other is moved through three arcs of 75 cm radii centered at the excitation point of the bar. These arcs are shown in figure 2 along with measurement points which are situated 15 degrees apart. The arcs in the XZ and YZ planes extend from 90 degree above to 90 degrees below the horizontal plane. The arc in the XY plane encompasses only 90 degrees. It is assumed that this quarter sphere is typical of the entire soundfield due to the symmetry of the bar and tube.

Seven directivity measurements are made, one of the bar without the tube, and six of the bar and tube together. Without the resonator tube, the frequency spectra of both mics are recorded and averaged 12 times over 9 seconds at each position of the directivity mic. These averages are started by a trigger from the reference mic. With the tube in place, the fin is rotated about the y-axis through six positions, from the horizontal, closed, position at 0 degrees to 150 degrees in steps of 30 degrees. At 90 degrees, the fin is vertical and the tube is fully open. At each fin position, the frequency spectra of both mics are again recorded and

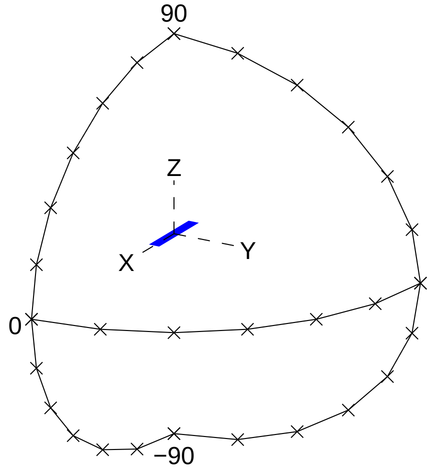

Figure 2: Three dimensional view of microphone positions

averaged 6 times over 5 seconds. This shorter time is due to the relatively short decay time of the bar with the open resonator tube.

The frequency spectra of two resonance conditions are shown in figure 3. It can be seen that three frequencies are prominent, the fundamental frequency f_0 measured at 628 Hz, the second partial at $2516\,\text{Hz} = 4\,f_0$, and the third partial at $5044\,\text{Hz} = 8\,f_0$. The data at these three frequencies are used in the directivity analysis.

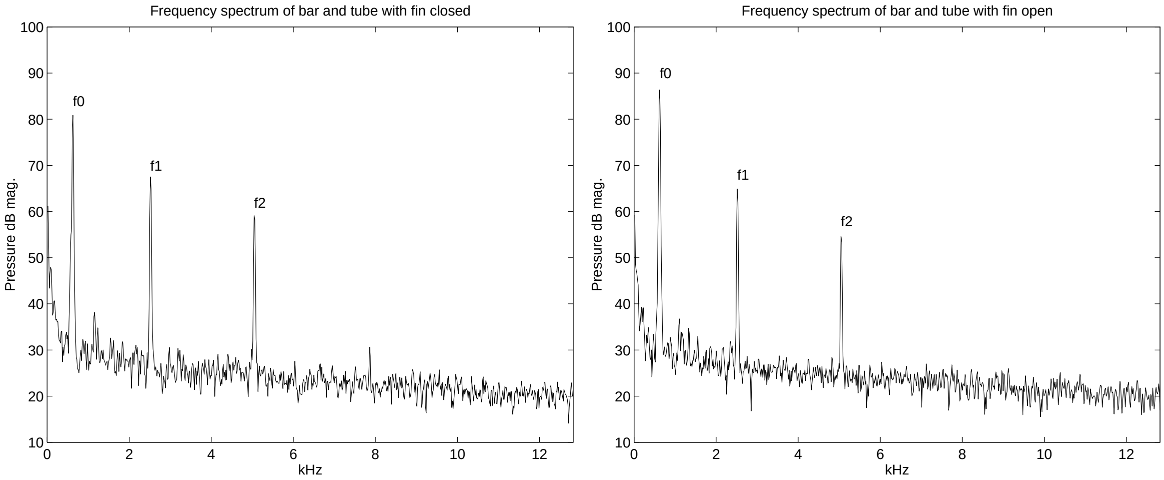

Figure 3: Frequency spectra with tube open and tube closed

Measurements from the reference microphone are used to correct any variations in the excitation of the bar. For each resonance condition, the variations in the bar's excitation are calculated as the difference between the fundamental frequency data and the mean of these data. These variations are subtracted from all three frequency data points of the corresponding directivity microphone measurements.

The resulting data with the variations of the striker removed can be plotted as normalized directivity. For the six resonance conditions involving the tube, all curves are plotted relative to the same dB value. Since the bar without the tube is measured with a different number of averages, the resulting curves are normalized to the highest dB value for that resonance condition. The polar plots of directivity are shown in figures 4 and 5.

4. RESULTS

Each polar plot shows directivity curves for the three resonance frequencies of the bar. Two sets of curves, one on the right and one on the left of each graph, show the results of two resonance conditions so that they may be compared. A perspective view of the bar is drawn in the middle to show its orientation. The first six polar plots in figure 4 juxtapose directivities of the bar and tube where the fin angles are supplementary. These are meant to simulate the entire 360 degree field with the fin in one position and show any change in directivity from one side to the other. The plots in the last row of figure 4 juxtapose the directivities of the bar and tube in the remaining two resonance conditions. The open-tube curves are on the left, and the closed-tube curves are on the right of each plot. The plots in figure 5 are arranged similarly with the open-tube resonance condition on the left and the no-tube condition on the right. Even though the plots of the resonance conditions in figure 5 are normalized to different maximum values, comparisons still can be made between their directivities and between the relative amplitudes at different frequencies.

5. ANALYSIS

Several observations can be made from this set of polar plots. First, the relative amplitudes of the resonance frequencies change as the mouth of the tube is opened. The amplitude of the fundamental increases by an average of 7 dB. At the same time, the first overtone is attenuated by an average of 9 dB, and the second overtone is attenuated 19 dB. The resonance of the tube has the effect of tuning the energy radiated from the bar to the fundamental frequency.

Second, as the resonator tube is added and opened, the directivity of the fundamental frequency can be seen to change from a dipole to a monopole pattern. This is most evident in the plots of the XZ plane. It has been shown that an unbaffled, free-free bar will radiate as an array of dipoles if the bar's height is small compared to the wavelength of sound radiated [2]. In this case, for the fundamental frequency, $k_0\,h$ is 0.109, which is much less than 1. For the second overtone, $k_2\,h$ is 0.878, which is still less than 1. It is also evident from the plots of the XZ plane that the dipole pattern of the first overtone f_1 becomes more pronounced as the fin turns toward the vertical.

Finally, examination of the second row of plots in figure 4 reveals that the amplitudes of the overtones f_1 and f_2 are slightly higher when the fin is opened 120 degrees than they are when

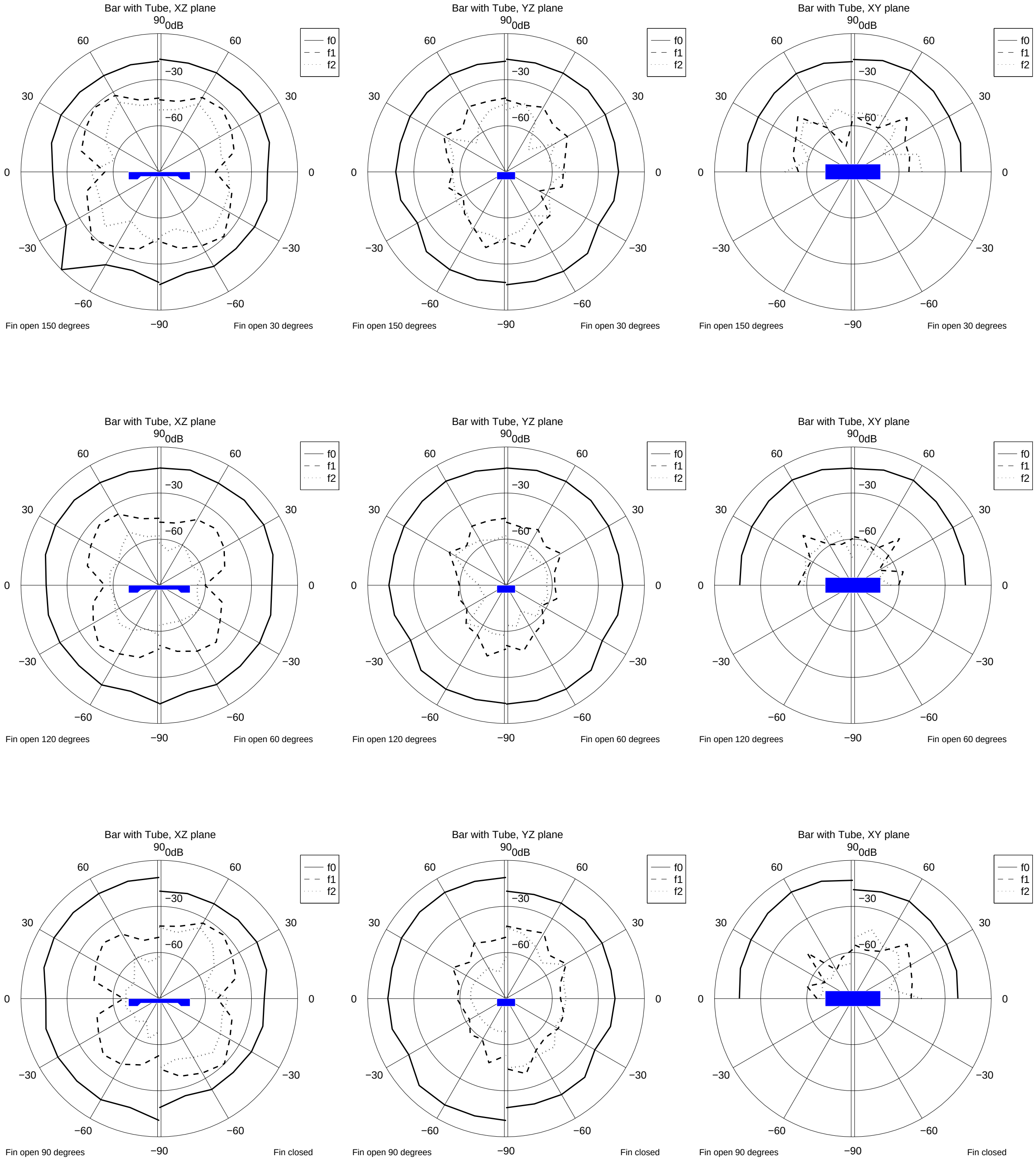

Figure 4: Normalized directivity

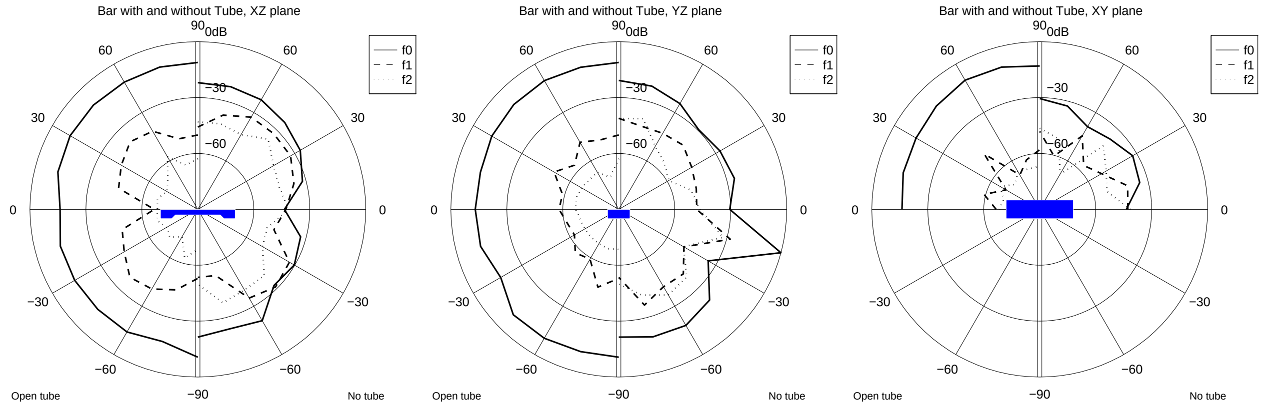

Figure 5: Normalized directivity

the fin is opened 60 degrees. This relationship appears to be consistent over the three plots in row two, suggesting that the position of the fin when it is nearly vertical could have an influence on the directivity of the bar and tube at higher frequencies. Further study is needed to verify this hypothesis.

6. CONCLUSIONS

These measurements show that the rotation of the fin at the top of the resonator tube affects not only the loudness of the fundamental frequency of the bar but also the relative amplitudes of the harmonics and the directivity of the radiated sound. This information will be useful in the development of a computational model of the sound radiated from a vibraphone. It can also be used to enhance the shimmering quality of the sound from the instrument itself.

7. REFERENCES

[1] N. H. Fletcher & T. D. Rossing, ‘The Physics of Musical Instruments’, Springer-Verlag, 1991.

[2] M. C. Junger, ‘Sound radiation by resonances of free-free beams’, J. Acoust. Soc. Am. **52**(1), Mar 1972.