JUNE 20 2019

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Proc. Mtgs. Acoust. 35, 035004 (2018)
https://doi.org/10.1121/2.0001011

Volume 35 http://acousticalsociety.org/

176th Meeting of Acoustical Society of America
2018 Acoustics Week in Canada
Victoria, Canada
5-9 Nov 2018

CANADIAN ACOUSTICAL ASSOCIATION
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Musical Acoustics: Paper 3aMU2

Physics of musical drum head damping using externally applied products

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Snare drums and tom-toms used in drum sets often produce an undesirable high frequency ringing sound when struck. Drummers have historically applied DIY damping solutions to address this ringing, placing objects such as wallets and tape on the heads. A variety of inexpensive commercial products is now available to dampen drums in a more controlled manner. The most commonly used products consist of small adhesive pads that can be placed directly on the drum head at desired locations, either singly or in combinations. An experimental investigation of the ringing drum head modes and the effects of the damping pads is reported. Decay rate measurements indicate that the (3,1) and (4,1) modes often contribute the most to the ringing sound, and that these modes are strongly affected by the damping pads. Another class of commercial dampener consists of thin annular rings of Mylar® that conform to the perimeter of the drum head. These free-floating rings produce a similar damping effect, but dissipate energy through a different physical mechanism. Experimental results for both types of dampeners are presented, and discussed in terms of viscoelastic and squeeze-film damping mechanisms respectively.

Published by the Acoustical Society of America

 https://doi.org/10.1121/2.0001011

1. INTRODUCTION

Snare drums and tom-toms used in drum sets often produce an undesirable high frequency ringing sound when struck forcefully. This ringing is especially noticeable at small distances and when close miking techniques are employed. Historically drummers have applied a variety of DIY dampeners to their drum heads, including strips of tape, cloth, or even their wallet, to address the problem. Today, many commercial products are sold to dampen this ringing sound in a more controlled manner, without changing the underlying sound of the drum appreciably.

Popular products include small, flexible, adhesive pads[1] that stick lightly to the head while the drum is played, and thin annular rings[2] that float freely on the head (Fig. 1).

The goal of this work is to determine if specific modes and/or frequencies are responsible for the ringing sound, and to what extent the dampening products are able to selectively affect these sounds without significantly altering the other modal decay rates and resonant frequencies.

Figure 1. Commercial damping products used in this work: a thin Mylar ring on a black drum head (for visibility) (left), and a blue MoonGel damper pad (right).

2. DRUM ACOUSTICS

A. NORMAL MODE THEORY

When a drum is struck, many resonant modes are excited, followed by free decay. In general, these modes start at different amplitudes and decay at different rates. As a result, the sound spectrum varies with time, and is dependent on both the excitation method and impact location.

With circular symmetry, ideal membrane's normal modes can be characterized by their number of nodal diameters (m) and nodal circles (n). The mode shapes and frequencies of the ideal circular membrane may be calculated analytically, with normal mode shape solutions given by Eq. (1), which shows that these shape functions ψ_{mn} are proportional to a Bessel function of the first kind in the radial direction, and a sinusoidal function in the angular direction.[3,4]

$$\psi_{mn}(r,\theta) \sim J_m(k_{mn}r)\begin{Bmatrix} \cos[m(\theta+\phi_{mn})] \\ \sin[m(\theta+\phi_{mn})] \end{Bmatrix} \tag{1}$$

The first twelve modes of an ideal membrane (without air loading) are shown in Fig. 2, with their (m,n) designations indicated above and ideal frequency ratios below each shape.[5] As implied in Eq. (1), modes containing nodal diameters ($m > 0$) are doubly degenerate, with nodes and antinodes swapping places via the sine and cosine solutions. Only one of each pair of solutions is depicted in Fig. 2. Although the frequencies of a real drum will deviate from the ideal case, a drum with a high degree of circular symmetry will still exhibit at least the first several of these modal shapes. As a result, the (m,n) designations are useful for identifying the drum head resonances studied here.

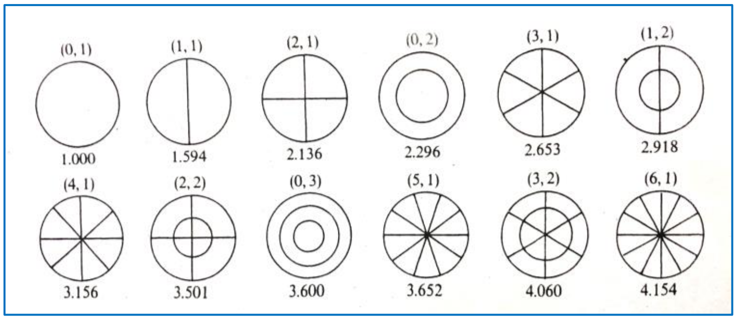

Figure 2. Modal patterns of an ideal drum head. Integer designations (m,n) give the number of nodal diameters and circles respectively. Frequency ratios relative to the fundamental are shown below each shape.

B. MODAL DEACAY RATES

Damping mechanisms and decay rates for a variety of drums, including timpani (kettledrums),[6-8] bass drums,[9] and drums from both India[10] and Myanmar,[11] have been described in the literature. Of greatest relevance to the work reported here is the paper of Rossing, et al.[12] on snare drums.

In a drum with no additional dampeners added, damping mechanisms include acoustic radiation, internal membrane dissipation, and membrane interactions with the bearing edge. In addition to being directional, acoustic radiation efficiency varies with mode shape and frequency. Modes containing only circular nodal lines (e.g. the fundamental) exhibit non-zero volume displacement and tend to radiate efficiently. Modes containing only nodal diameters have zero net volume displacement and no monopole moment. The cross-flow of air, parallel to the membrane surface, reduces the radiation efficiency as the number of nodal diameters (m) increases. This lower radiation efficiency by itself correlates with a longer decay time. However, internal losses associated with flexing of the membrane tend to *increase* with frequency, acting to lower the decay times. Thus, competing effects act to determine which modes of a given drum will ring the longest.

3. EXPERIMENTAL METHODS

Commercial tom-toms and snare drums with just a single head in place were used in this work. These drums had diameters of 12” and 14”, with commonly used single-ply Mylar® drum heads employed throughout.[13] Single heads were chosen as a convenient way to begin this study. Furthermore, the high frequency ringing sounds being investigated are believed to come from modes that do not couple strongly between the two heads when both are in place.[14] This hypothesis was verified qualitatively in the lab, but should be investigated more thoroughly in the future.

Time-dependent spectra were obtained by striking the drum head at an off-center location, with a microphone placed a few inches above the head. The microphone signal was fed into a spectrum analyzer.[15] The resulting data were displayed in a “waterfall” format by the spectrum analyzer, and also transferred to a spreadsheet program for further analysis of the modal amplitudes and decay rates. A typical waterfall spectrogram is shown in Fig. 3.

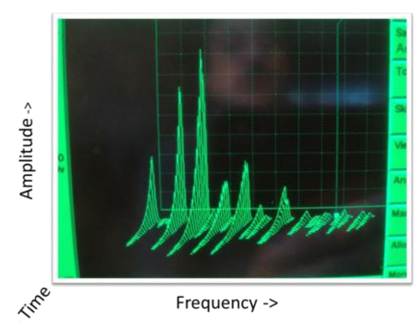

Figure 3. A typical waterfall display showing time evolution of the acoustic signal from a drum head impact. The fundamental (0,1) resonance is on the far left, followed by the (1,1) and (2,1) shapes, which in this case are more prominent than the fundamental. With the linear amplitude scale shown here, exponential time decays are qualitatively observed.

A data slice representing a single mode's amplitude vs. time (Fig. 4) shows exponential decay when plotted on a linear vertical scale, and linear decay when the vertical axis employs a log scale. From the log scale data, decay rates in dB/s could be determined.

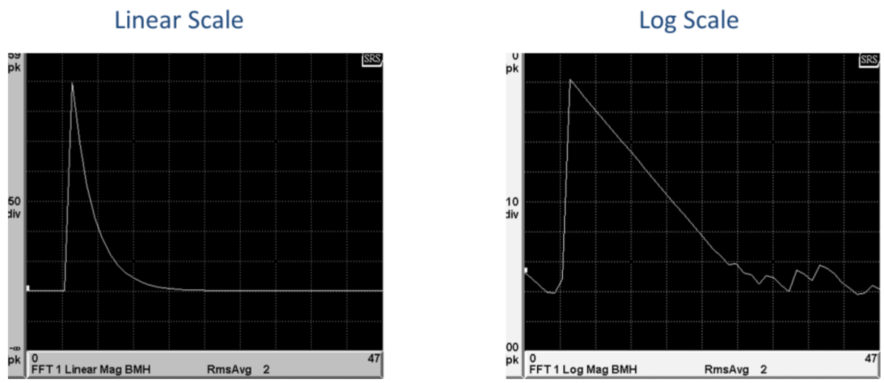

Figure 4. Sample amplitude vs. time data. Slice is of a (0,1) fundamental signal at f = 184 Hz. The exponential decay (left) displayed on the linear vertical scale becomes a linear decay on the semi-log plot (right).

Electronic speckle-pattern interferometry (ESPI)[16] was used to record images of drum head deflection shapes when driven acoustically at resonant frequencies. These images were used to assign (m,n) values to the frequencies observed on the spectrum analyzer. The symmetry of the ESPI images was also used to verify that the drum head tension was uniform.[17]

4. EXPERIMENTAL RESULTS

A. UNDAMPED ("OPEN") DRUMS

Initial studies were performed on drums without dampeners applied. It was observed that the resulting spectra varied with membrane tension, beater properties (size, weight), striking technique and contact time, and radial location of the impact. Generally, production of higher modes was favored by high tension, a small, hard beater, short contact time, and impact near the rim of the drum, as would be expected.[18] Figure 5 shows a comparison between high and low tension membranes, with the other factors held approximately constant. In the high tension case, the (3,1) mode rings the longest (i.e. extends the farthest along the time axis). This behavior is not observed in the low tension case.

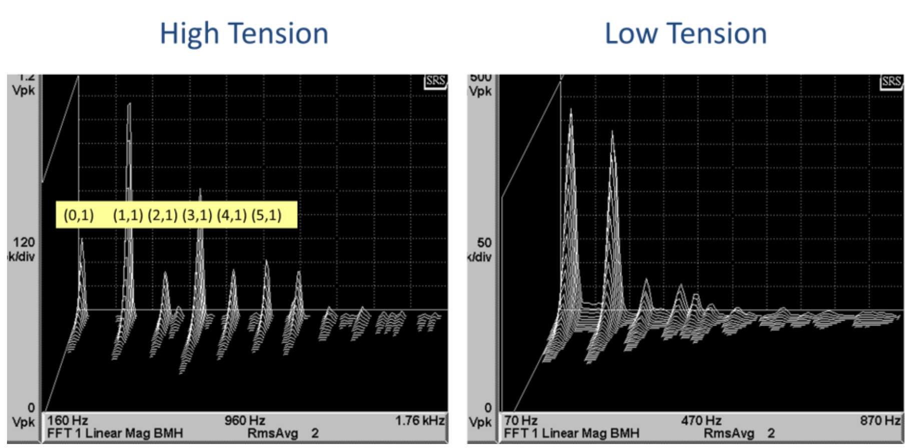

Figure 5. Waterfall displays for an "open" drum head (no added dampeners) under high tension (left) and low tension (right). The high tension case reveals a larger number of distinct higher mode resonances, along with an overall increase in the frequencies. Note that the horizontal frequency scales in the two plots are different.

B. DAMPING WITH PADS

The commercially sold adhesive pads make use of *viscoelastic* damping.[19] Viscoelastic materials, such as rubber, exhibit hysteresis in their stress-strain characteristics, with some energy dissipated as heat during each cycle. Damper pads using this mechanism can stretch, compress, and bend in response to acceleration and curvature of the underlying medium. The configuration used on the drum head is an example of single-layer damping (also referred to as *unconstrained* or *extensional* damping), as shown in Fig. 6.

Figure 6. Diagram illustrating single layer (extensional) damping by a viscoelastic material on a substrate (left). On the right is a photograph of a MoonGel pad on a drum head prepared for high speed video recording.

High-speed video[20] was recorded of the viscoelastic pads on the drum head during, and shortly after, a stick impact. Videos shot at 15 k frames per second were played back to display the motion slowed down by a factor of about 400. These videos clearly showed the periodic distortions of the flexible pad characteristic of single layer damping. The bottom surface of the lightly adhesive pads stayed in contact with the membrane surface throughout.

These viscoelastic damper pads may be used singly, or in combinations. When only one is used, placement is determined by the desired radial distance. Typically the gels are located within an inch or two of the rim. This placement keeps most of the head free for sticking, and also influences the modes which will be most highly damped (Fig.7). Analysis of the radial Bessel function of Eq. (1) shows that as the number of diameters, m, increases, the antinodes move closer to the rim of the drum in the radial direction. These modes with higher m-values are more prominent when the drum is struck near the rim, and equivalently, they are more readily damped by a pad placed near the rim.

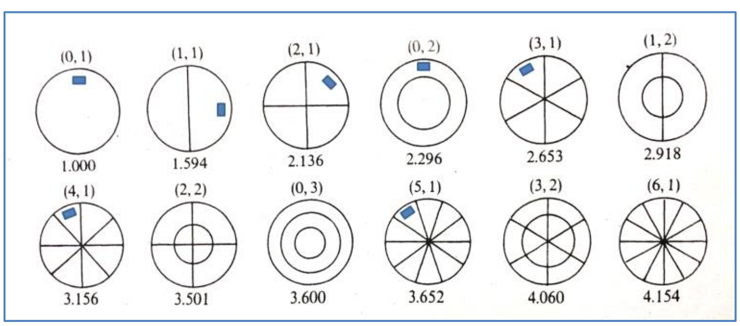

Figure 7. Drum head mode shapes with typical gel placement indicated (in blue) on a few of the acoustically significant shapes. Note that placement near the rim puts the viscoelastic pad closer to the antinodes of modes (3,1), (4,1), and (5,1) than it does to the antinodes of the (0,1), (1,1), and (2,1) modes.

Although not shown in these mode shape drawings, the membrane modes containing at least one nodal diameter ($m > 0$) are doubly degenerate in a uniformly tensioned head. The orientation of such modes in a given case will be determined by the location at which the head is struck (assuming it is not struck directly in the center). The strike location will impose an antinode orientation as shown in Fig. 8. A damper pad vs. stick angle of 180º ideally damps modes of all m; at an angle of 90º only mode shapes of even m are preferentially damped.[21] Although these symmetry relations are readily verified in the lab, in practice a snare drum or tom-tom will be struck with two sticks at various positions that are generally not based on damper pad placement. This pad placement is more relevant with a large drumhead, such as on tympani, as discussed by Campbell and Greated.[21]

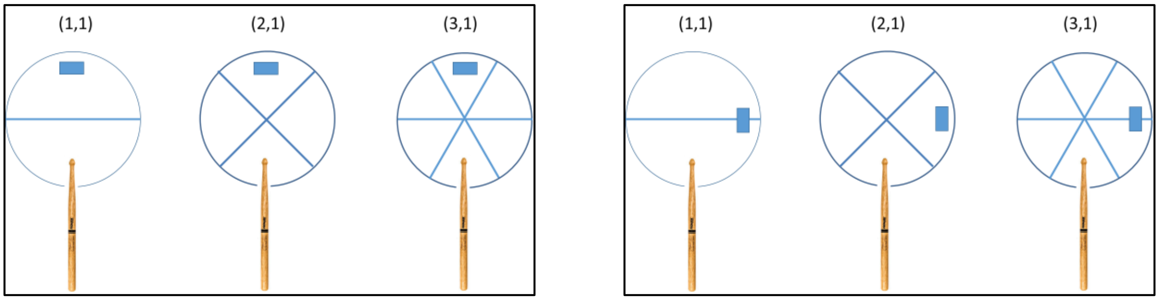

Figure 8. 180º angle between stick and damping pad (left) and 90º angle (right). Angular orientations of the modes are determined by the stick location, resulting in antinodes at the impact position. The viscoelastic pad (in blue) damps a mode more when it is near an antinode and less when it falls on a nodal line. On the right, the pad falls on a nodal line for all odd values of m.

Similarly, a stick-to-pad angle of 120º will preferentially damp the (3,1) mode shape. An angle of 60º would have the same effect, but to locate the pad as far from the stick as possible, the ideal damping angle may be taken to be $180° \, (m-1)/m$, for a mode shape with m nodal diameters. This particular case is examined further in Section 4.

C. DAMPING WITH MYLAR RINGS

Annular rings of thin Mylar® for damping are sold by most drum head manufacturers, as the same type of polyester film is used for the majority of commercially produced heads. The rings are manufactured such that their outer diameter matches the diameter of a given drum (common sizes include 12, 13, 14, and 16 inches). Typical ring widths are 1, 1.5, and 2 inches, and may be used singly or in combinations, with smaller widths placed on top of larger widths. Unlike the viscoelastic pads, these annular rings maintain the circular symmetry of the drum. For this reason, only the radial position of the stick impact causes changes to the resulting sound spectrum.

The motion of the annular rings on a drumhead that was struck in a typical manner was observed with the high-speed video as described above for the viscoelastic pads. The rings were seen to lose contact with the head, flopping up and down over the membrane in response to its motion. This behavior is characteristic of a type of air-layer damping referred to as *squeeze-film damping* or *gas pumping*.[19]

The rings are loosely held in place on the drum by gravity, often by a component of the gravitational force in the common case of drums that are angled a bit from horizontal. The air damping motion occurs when the membrane accelerates up and down, and when the surface bends. Both of these effects occur near antinodes of the deflection shapes and across nodal lines, where membrane motions are out of phase with each other. For rings near the perimeter of the drum head, these motions may be expected to cause selective dampening of the modes with larger numbers of nodal diameters, and whose antinodes are closer to the perimeter. Both of these conditions are met by modes of higher m-value (Fig. 9). In contrast, the annular ring has little effect on the (0,1) fundamental mode, as most of this mode's motion is near the center of the head.

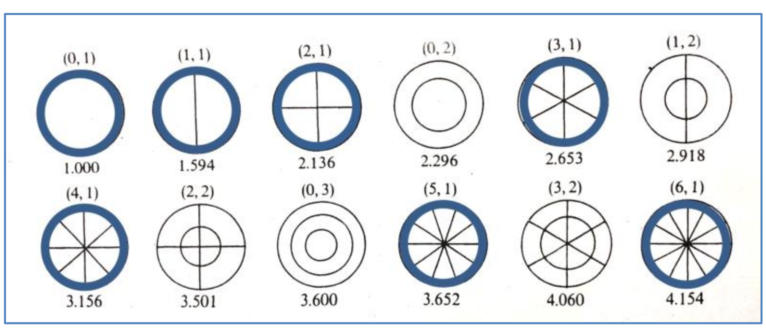

Figure 9. Drum head mode shapes with annular rings (in blue) added to a few. Modes with larger numbers of nodal diameters will be most strongly affected by the addition of free-floating material near the perimeter.

D. COMPARISONS OF DAMPING METHODS

Figure 10 shows four waterfall-display spectrograms of a 12” tom-tom tuned to a fundamental frequency of 148 Hz. The three plots with dampeners show significant reduction of high frequency modes relative to the open (undamped) case. The stick-to-pad angle of 180° clearly shows a greater reduction of modes when compared to the 90° case, as expected based on the discussion presented in Section 4B.

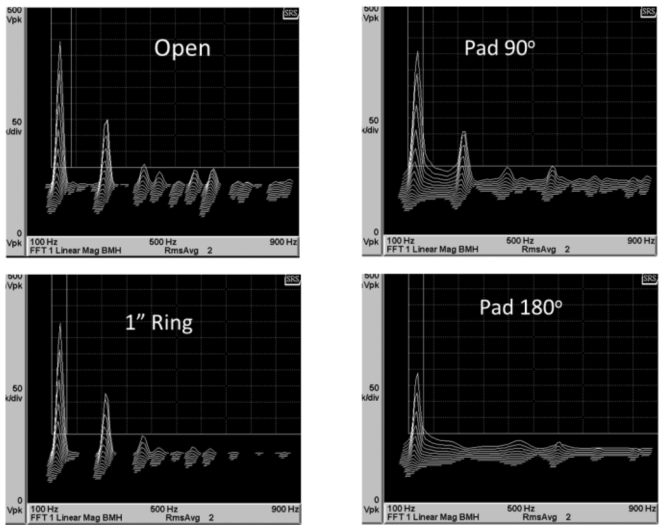

Figure 10. Data from a 12” tom-tom, with (0,1) tuned to f_1 = 148 Hz. Upper left plot is for undamped drum.

Figure 11 shows spectra for a 12” tom-tom tuned to a high tension (f_1 = 184 Hz). Looking at the time axis, the open case (on the left) shows the (3,1) mode ringing the longest, as indicated by the horizontal yellow line. Note that the ringing mode need not have the largest *initial* amplitude. In the center panel, the 1” muffle ring has both decreased the initial amplitude of the (3,1) mode shape and shortened its decay time. The higher frequency modes are also damped significantly. The right panel shows the same drum with a single damper pad at 120° relative to the stick position. Again, both the amplitude and decay time of the (3,1) mode are reduced such that it does not ring longer than the lower modes.

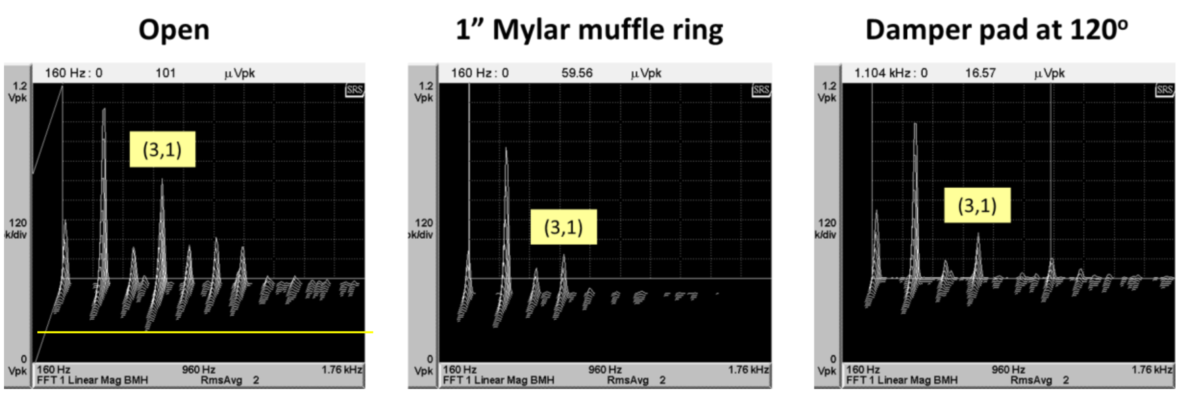

Figure 11. A 12” tom-tom at high tension (f1 = 184 Hz). The (3,1) mode rings the longest when open, but not when either of the two types of dampeners is employed.

Numerical values of the linear decays rates, expressed in dB/s, are shown in Table 1 for the first five modes of the drum used for Fig. 11. In the open drum, the (3,1) mode, with a frequency of about 700 Hz, has the smallest decay *rate* (17.8 dB/s) and thus the longest decay *time*. The damper pad at 120° and the muffle ring both increase the decay rate of the (3,1) resonance by about 6 dB/s, thus decreasing the ringing time. No mode below (3,1) has as much as a 2 dB/s increase in decay rate when the dampeners are used. The next higher frequency mode, (4,1), has the next largest increase in decay rate, at nearly 3 dB/s. In all cases shown, the two dampeners had nearly identical effects on these lowest five modes of the drum. As desired, both devices acted preferentially to dampen the most strongly sustaining mode, albeit via different physical mechanisms. Finally, although not tabulated here, it was observed that neither damping product altered the effective mass or stiffness of the membrane enough to alter the frequencies of the acoustically significant modes, when used in the intended manner. A viscoelastic pad placed at the *center* of the drum did in fact lower the fundamental frequency, although this is clearly not a practical location for such a damper pad.

Table 1. Decay rates in dB/s for the lowest five modes of a 12" tom-tom, derived from the data of Fig. 11.

	Decay Rate (dB/s):				ΔdB/s	
Mode	**Open**	**Ring**	**Pad**		**Ring**	**Pad**
0,1	23.9	24.0	23.8		-0.1	-0.1
1,1	23.9	24.0	24.0		0.1	0.1
2,1	22.0	23.8	23.9		1.8	1.9
3,1	**17.8**	**23.9**	**24.0**		**6.1**	**6.2**
4,1	21.1	24.0	23.9		2.9	2.8

5. CONCLUSIONS

The pattern of initial mode amplitudes and modal decay rates observed in the drum head spectrograms varies significantly with applied membrane tension. Relatively high tensions favor audible ringing sounds produced by the higher diameter-only modes, often the (3,1) and (4,1) shapes. In addition, the beater used and its location of impact influence the time-dependent spectrum that is produced. Smaller beaters, shorter contact times, and locations near the rim all tend to favor the higher frequency modes, which contribute to the sustained ringing sound that may be heard. Drums tuned to lower tensions were less likely to exhibit this ringing sound when played in a typical manner.

Both types of damping products studied here (flexible pads and thin Mylar® rings) act to *selectively* shorten the decay times of the higher frequency ringing modes, despite the fact that their operation depends on different physical mechanisms (viscoelastic vs. squeeze-film damping).

Future research should include repeating the measurements described in this paper on drums with both heads in place, as snare drums and tom-toms are typically configured. Additionally, a study of commercially available drum heads that contain *built-in* dampening materials would provide worthwhile comparisons with the add-on products discussed here.

ACKNOWLEDGMENTS

The authors wish to thank Professor Rachel Pepper and Tom Daligault of the University of Puget Sound Physics Department for use of the high speed camera.

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