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Acoustic Analysis of Timpani: Specific Mode by Striking Point

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ABSTRACT

The timpani is the musical instrument in the percussion family and is usually considered as the most important drum in modern orchestras. Timpani have a strong sense of pitch and various tone colors. Striking closer to the edge of the drumhead, the sound will become thinner. In contrast, striking closer to the center of the drumhead a more staccato sound can be produced. The timpanist changing the striking point during the course of the play produces different subtle tone colors. In this study, the acoustic features of striking points through modal analysis were investigated. It is well known that the normal striking point area encompasses a distance of about one-third to one- fourth from the rim and the center of the drumhead. However, the best striking point that has the most resonance and fullness of overtones still remains an open research problem.

Keywords: normal modes, tone color, circular membrane, higher order mode

INTRODUCTION

The timpani is a musical instrument usually considered as the most important drum in modern orchestras. It also known as the kettledrums and is constructed of a large copper bowl with a drumhead made of animal skin stretched across the top. The timpani was the first drum to be used in the orchestra joining the ensemble over 300 years ago and it is the only orchestra drum that can produce defined pitch notes [1][2]. On account of their attractive properties, many physicists and acoustic researchers investigated its acoustic characteristic from the past.

The timpani has a strong sense of pitch and it can emit various tone colors due to the striking point. When striking closer to the edge of the drumhead, the sound will become thinner. Meanwhile, striking closer to the center of the drumhead, more staccato sound can be produced. The timpanist changing the striking point during the course of the play to produce different subtle tone colors.

It is well-known that the normal striking point area encompasses a distance of about one-third to one-fourth from the rim and the center of the drumhead. The tone and colors vary within those areas and with experience a timpanist can learn to use the appropriate sound for a given passage. However, the best striking point that has the most resonance and fullness of overtones still remains an open research problem.

In this work, the studies on 4 striking points based on modal analysis and on the measure of acoustic radiation of timpani were performed.

TIMPANI PHYSICS

The word “timpani” is taken from the Latin word “tympanum” meaning vibrating membrane. The timpani’s heads, which used to be made primarily of calfskin, when struck, are made to vibrate. Timpani are often called kettledrums because the bowls, which are made from copper, resemble kettles. Timpani range in size from 32 inches to 23 inches. The standard sizes are 32”, 29”, 26”, and 23”. Each drum has a melodic range of about a 5th interval.

The vibrations of the timpani's drumhead can be modeled by the wave equation [3]

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$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\Phi = \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\Phi \quad (1)$$

where c is the speed of waves travelling on the drumhead. The constant c is directly related to the tension of the drumhead and the corresponding pitch that is generated by hitting the drumhead with a mallet. The characteristic sound of the timpani is determined by its vibrational modes and their corresponding frequencies. The product solutions that describe the vibrational modes of the circular drumhead from Eq. (1) are therefore

$$\phi_{mn} = J_m\left(\frac{z_{m,n}}{c}r\right)[A_{mn}\cos(n\theta)+B_{mn}\sin(n\theta)][\alpha_{m,n}\cos(c\lambda_{m,n}t)+\beta_{m,n}\sin(c\lambda_{m,n}t)] \quad (2)$$

where J_m is Bessel function, other symbols are defined in [3]. Different combinations of *m* and *n* in the solution given by equation (2) form so called "normal modes" of the membrane. Membrane's nodes are circular lines concentric to the circumference and straight lines that correspond to the diameters of the membrane itself as shown in Figure 1. Each partial composing the sound of the instrument corresponds to a specific membrane vibration mode. The number and the type of nodes they are made of conventionally define vibration modes. For example is called (0,1) the first vibration mode of an ideal membrane, characterized by a circular node correspondent to the circumference itself with no diametrical node. Fletcher and Rossing [4] investigated vibration modes of the timpani using modern instrumentations. They discovered that all the vibration modes with only diametral nodes stay in harmonic ratio one to the other and that (1,1), (2,1), (3,1), (4,1), (5,1) vibration modes stay respectively in a 1, 1.5, 2, 2.44 (about 2,5) and 2,90 (about 3) ratio with the fundamental mode (1,1).

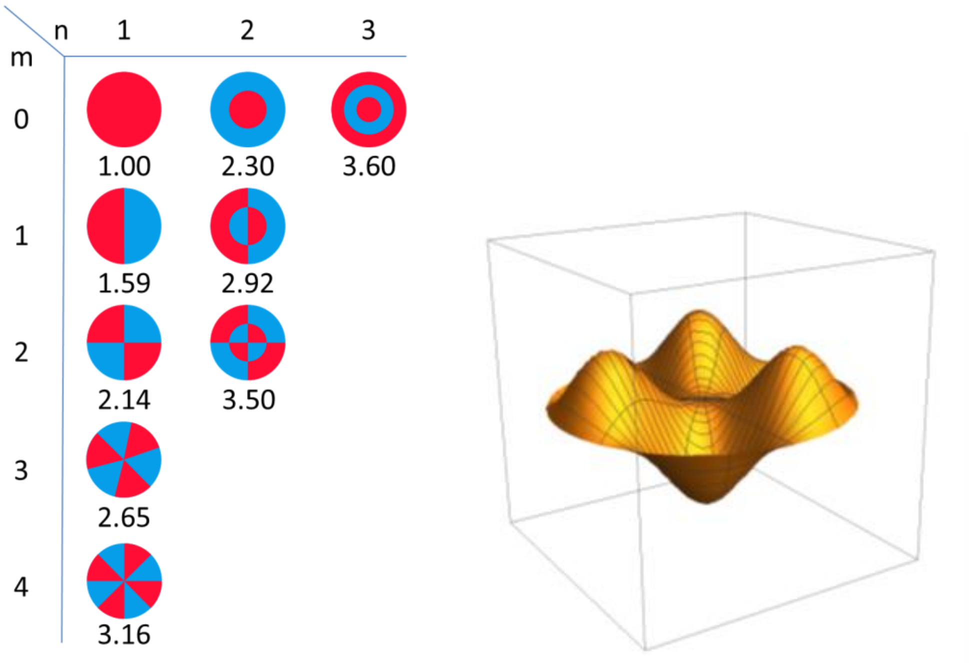

Figure1. *Normal modes of the circular membrane and sound distribution of (3,1) mode,*

EXPERIMENTAL SETUP AND THE RESULTS

To examine the differences in tone color due to striking point, the experimental was performed in the Anechoic Chamber as shown in Figure 2. The 32" timpani tuned on F_2 (87.3[Hz]) was used in the experimental. Sound radiation from timpani was recorded by one microphone located 65 cm away from the membrane. Position of the striking points on the membrane were determined as shown in Figure 3. The striking point along a circle with between two twelfths and five twelfths the radius of the entire membrane. For simple we referred to (I), (II), (III), (IV) position, respectively. Note that, (II) and (III) are the position which has a distance of one-third (four twelfths) to one-fourth (three twelfths) from the rim and the center of the drumhead, namely the normal striking point area encompasses. For this consideration, the distance between those striking point was set up at 6.6 cm.

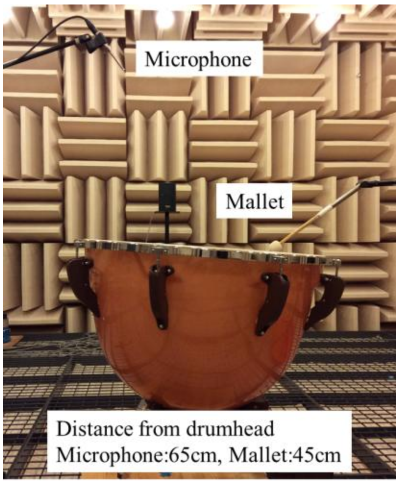

Figure2. *Experiment setup*

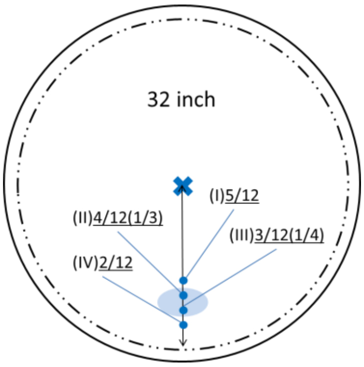

Figure3. *Striking points on the timpani*

The timpani sound involves the vibrational modes of a circular membrane, however in this study, 5 vibration modes namely (1,1), (2,1), (3,1), (4,1) and (5,1) were studied. The 32" size of timpani was used which is tuned to 87.3[Hz]. Therefore, the fundamental mode (1,1) is 87.3[Hz] and the frequencies found corresponding to the above vibration mode are 130.8[Hz], 173.8[Hz], 220.7[Hz] and 261.7[Hz], respectively.

Figure 4 shows the modal analysis of our experiment results when the timpani's mallet strike at (I), (II), (III) and (IV) position. The green bar represents the sound pressure level of the sound occurring instantly when a timpani mallet was stroked while the orange bar is the sound pressure level of the sound occurring after 1 second. It can be see that the difference of SPL between the green bar and the orange bar is small at (2,1) and (3,1) mode while they large at (4,1) and (5,1) mode.

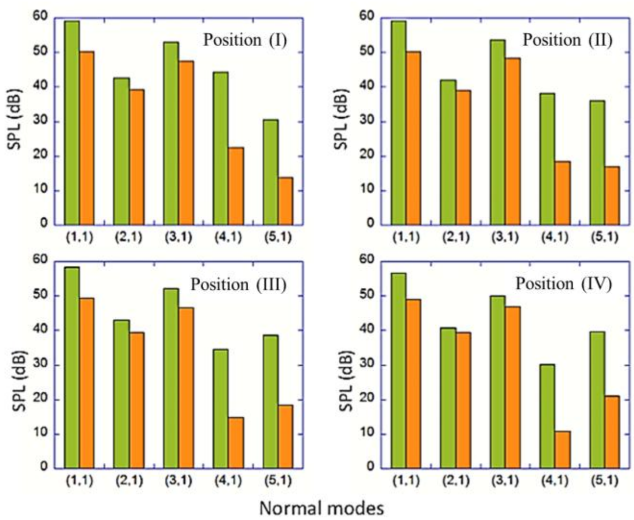

Figure4. *Modal analysis based on the experiment result.*

Green color and orange color are the SPL of the sound instantly and 1 second after striking.

In order to find the different acoustic features of sound depending on the mallet strike position, the SPL difference between the normal modes and (1,1) mode were calculated while the SPL of fundamental mode (1,1) was normalized at 1. The result is shown in Fig. 5. The upper figure represents the sound pressure level occurring instantly when a timpani mallet was stroked while lower one is the sound pressure level of the sound occurring after 1 second. The color of green, orange, red and dark green at each mode represent the SPL when the timpani's mallet strike at (I), (II), (III) and (IV) position, respectively.

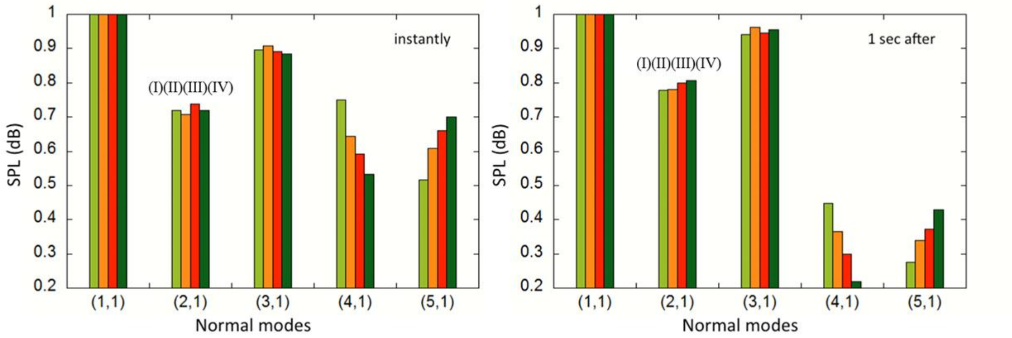

Figure5. *Modal analysis based on the experiment result.*

It can be seen from Fig. 5 that SPL of mode (1,1) , (2,1) and (3,1) are the almost same corresponding to the strike position. Therefore, it seems reasonable to say that mode (1,1), (2,1) and (3,1) are the dominant factor of timpani's tone color. Note that, mode (3,1) is a harmonic overtone of fundamental mode, therefore (3,1) and fundamental mode will give a strong sense of pitch.

In the other hand, the change in SPL of (4,1) and (5,1) mode are very interesting. According to SPL of those modes, we can clearly appreciate differences in sounds of timpani. It is apparent from Fig. 3 that mode (4,1) and (5,1) are low proportion and greatly decreases with time. Thus, the sound without these modes will be thin and sharp, like a staccato sound of violin. Note that, the mode (4,1) and (5,1) are the musical pitches A_3 and C_4.

By the way, the musical pitch of the normal mode (1,1), (2,1), (3,1), (4,1) and (5,1) is F_2, C_3, F_3, A_3 and C_4, respectively. The point to observe is that mode (1,1), (4,1) and (5,1) are the component of F major triad which is stable consonance. Figure 5 clearly shows that according to the strike position, (4,1) having a SPL inversely proportional to those of (5,1). When striking closer to the center of the drumhead, with high SPL of (4,1) and low SPL of (5,1) the sound will become rich tone. On the contrary, when striking closer to the edge of the drumhead, with low SPL of (4,1) and high SPL of (5, 1) the sound will become thin.

EXPERIMENTAL SETUP AND THE RESULTS

In this work, to examine the differences in tone color due to striking point, the studies on 4 striking points based on modal analysis and on the measure of acoustic radiation of timpani were performed. Position of the striking points on the membrane were determined as (I),(II),(III),(IV) position, in which (II) and (III) are the position which has a distance of one-third to one-fourth from the rim and the center of the drumhead. The timpani sound involves the vibrational modes of a circular membrane (1,1), (2,1), (3,1), (4,1) and (5,1). Mode (1,1), (2,1) and (3,1) are the dominant factor of timpani's tone color. Mode (1,1), (4,1) and (5,1) are the component of F major triad. The tone color of timpani various depend on the sound pressure level of (4,1) and (5,1) mode. Namely, when striking closer to the center of the drumhead, with high SPL of (4,1) and low SPL of (5,1) the sound will become rich tone. On the contrary, when striking closer to the edge of the drumhead, with low SPL of (4,1) and high SPL of (5,1) the sound will become thin.

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