Harmonicity in the pitched drums

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Abstract

Only the percussion instruments which can produce rich harmonic sound can generate good music. This paper studies about the harmonic content in the strokes of two drums. It is found that pitched drums are rich in harmonics, whereas unpitched drums do not produce rich harmonics. This article is aimed as an experiment in an undergraduate acoustic laboratory and hence a detailed account of how to differentiate pitched and unpitched drums are given.

Keywords: Music and musical instruments, Drums, Pitch.

Resumen

Sobre el contenido armónico en los golpes de dos tambores. Se encuentra que los tambores afinados son ricos en armónicos, mientras que los tambores sin afinación no producen armónicos ricos. Este artículo tiene como objetivo ser un experimento en un laboratorio acústico de pregrado y, por lo tanto, se brinda una descripción detallada de cómo diferenciar los tambores afinados y sin afinar.

Palabras clave: Música e instrumentos musicales, Tambores, Cabeceo.

I. INTRODUCTION

The membranes on the drums are the vibrating systems which produce the sound. The membranes are the two dimensional versions of the strings. So instead of drums we will consider some basic concepts of sound produced by the vibration of the strings (which is simpler than membranes) [1, 2, 3]. When a string vibrates, travelling waves $\Psi_1(x,t)$ and $\Psi_2(x,t)$ are formed at both ends which travel in the opposite direction represented by [4]

$$\Psi_1(x,t) = D\sin(kx + \omega t), \tag{1}$$

$$\Psi_2(x,t) = D\sin(kx - \omega t), \tag{2}$$

where D is the amplitude, ω is the frequency, λ is the wavelength, $k = \frac{2\pi}{\lambda}$, and x is the position and t is the time. Let $\Psi(x,t)$ is the resultant wave formed by adding $\Psi_1(x,t)$ and $\Psi_2(x,t)$. Then

$$\Psi(x,t) = D(\sin(kx + \omega t) + \sin(kx - \omega t)). \tag{3}$$

Using the trigonometric relation

$$\sin(A+B) + \sin(A-B) = 2\sin A \cos B, \tag{4}$$

we get

$$\Psi(x,t) = 2D\sin kx \cos \omega t. \tag{5}$$

Here $\Psi(x,t)$ is the standing wave which vibrates by remaining stationary in a position. These standing waves create pressure variations in the nearby air around the string. The disturbances created in the air and the air molecules move in the same direction and reach our ear. Let us consider two such waves $\chi_1(x,t)$ and $\chi_2(x,t)$ with frequencies ω_1 and ω_2. Here our x component of the waves remains constant and let $H = 2D\sin kx$ and we have [5]

$$\chi_1(t) = H\cos \omega_1 t, \tag{6}$$

$$\chi_2(t) = H\cos \omega_2 t. \tag{7}$$

We have

$$\cos A + \cos B = 2\cos\frac{A+B}{2}\cos\frac{A-B}{2}, \tag{8}$$

and using this the resulting wave consists of a wave of frequency ω_n modulated by another wave of frequency ω_m given by [6]

$$\chi(t) = 2H\cos\omega_n t\cos\omega_m t, \qquad (6)$$

where $\omega_n = \frac{(\omega_1+\omega_2)}{2}$ and $\omega_m = \frac{(\omega_1-\omega_2)}{2}$. When the frequencies of two waves $\chi_1(x,t)$ and $\chi_2(x,t)$ are close to each other the resultant waves are called beats. When two sound waves with frequencies ω_1 and ω_2 enter in the ear, the components of cochlea vibrates not only at ω_1 and ω_2 but also at some of its combinations like $\omega_1-\omega_2$ [7]. Different patterns of vibrations are converted to electrical signals and they reach our brain and we recognize the particular sound. The Fig. 1 shows two waves at frequency 6 Hz and 5 Hz and the resulting wave after superposition. The beats formed in this manner will have a frequency $\omega_1-\omega_2=2\omega_m$ (In the example it is 1Hz). Plomp and Levelt studied the effect of beats formed from two pure tones (a single frequency sound). They played two pure tones simultaneously and allowed to hear it by a group of people and found that when the two tones have same frequency listeners heard a single pleasant tone [8].

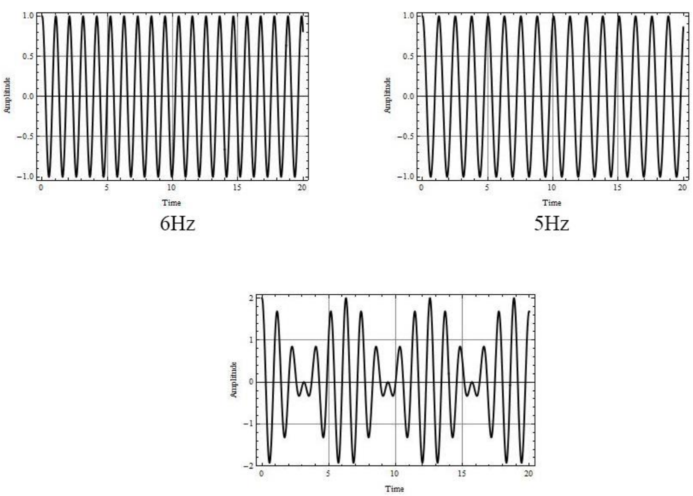

FIGURE 1. Beats formed from two waves at 6Hz and 5Hz.

The study further showed that as the second frequency increased keeping the first one fixed, the listeners heard uncomfortable sound with variation in amplitude (beats) and on further separation two tones are heard as separate. Thus, the formation of beats creates unpleasant variations in loudness. In string and membrane based instruments beats are formed often. In real drums, factors like changes in the thickness of the membrane, variations in the circular shape of the drum head etc creates some modes with frequencies of very small interval and they form beats which are removed by tightening the drum head or other techniques by the artist [9]. The frequencies generated by other modes do not line up in a series of a common lowest frequency and thus in ordinary drum sound does not have a definite pitch. This paper evaluates the strokes of two drums and their frequency ratio of different modes. The details of the drums under study in this work are given in next section.

II. METHOD OF STUDY

A large collection of musical instruments contribute to the rich musical culture of India. Out of the different types of instruments, drums are given prominent role in art forms and orchestra. The drum Mridangam, capable to produce good sense of pitch is studied in comparison with drum Chenda which is incapable to give clear pitch. The details of the drums are given below.

A. Mridangam

Mridangam is a commonly used drum in South Indian classical music [10] and a typical Mridangam is shown in Fig 2. It is made with jack wood and the drum head is covered with animal skin. A black paste made with fine powder of puranakeedam stone (which is available in local area) and rice is pasted at the centre of the drum head. It is a popular drum found in many cultural event and known for its pitched sound.

FIGURE 2. A Mridangam used in Kerala.

B. Chenda

It is one of the most famous percussion drum played in Kerala in ensembles and art forms [11]. The drum with two heads is made with wood and animal skin. Different layers of the animal skin are used to make a thick membrane to produce the typical tonal quality of the drum.

FIGURE 3. A typical Chenda played in Kerala.

Fig. 3 shows a Chenda played commonly in Kerala. Chenda is employed in many famous ensembles of Kerala as a rhythmic drum.

II. METHOD OF STUDY

This study is done after the collection and conversion of sound samples of two drums into waveform audio format. The sound samples of the drums are named as M and C. The MIR toolbox (working in Matlab) which is freely available in the website [12] is used for plotting power spectra of drum sound samples [13]. After the download, the MIR toolbox is installed using the **set path** option from **file** menu in Matlab. Use **Add folders with subfolder** option and select the MIRtoolbox folder and save the path. To plot power spectrum of each sample the following comment is used.

A. mirspectrum(filename, dB)

The power spectra of strokes of the two drums are plotted and dominant peaks in the spectra are found manually by placing the mouse pointer at each peak. The frequency ratios of peaks are found with respect to the first peak in the spectra. Peaks in the spectra with amplitudes less than 0 dB are not included in the study. For all strokes, the inharmonicity feature which indicates the amount of peaks that are not multiples of fundamental is also calculated. To calculate inharmonicity the below comment is used.

B. mirinharmonicity(filename)

The value of this feature remains between 0 and 1. The inharmonicity is calculated based on single fundamental frequency in the strokes.

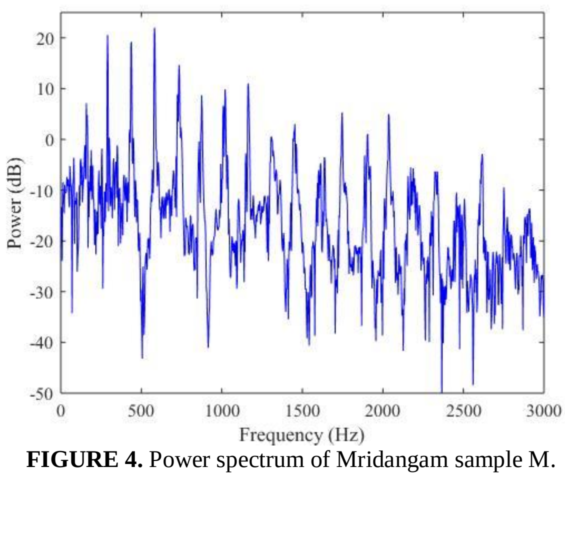

FIGURE 4. Power spectrum of Mridangam sample M.

III. RESULTS

In Mridangam, the lowest peak with feeble amplitude and many distinct higher peaks with integer relation are seen. The power spectrum of Mridangam is given in Fig. 4. Unlike Mridanam, the peaks are indistinct in Chenda. The power spectra of samples C of Chenda is shown in Fig. 5. The observed frequencies of different peaks in the spectra of drums are given in Table I.

TABLE I. The frequencies present in the spectra of strokes of drums.

Peak Number	*M (Hz)*	*C (Hz)*
1	158.8	944.8
2	290.7	1484
3	438.7	2069
4	581.4	2409
5	734.8	2756

The inharmonicity is inversely related to harmonicity of the strokes of the drums. The obtained values of inharmonicity are shown in the Table II. The obtained results indicate that the Mridangam stroke is the most harmonic.

TABLE II. The inharmonicity of different strokes of drums.

Sample	*Inharmonicity*
M	0.2903
C	0.46162

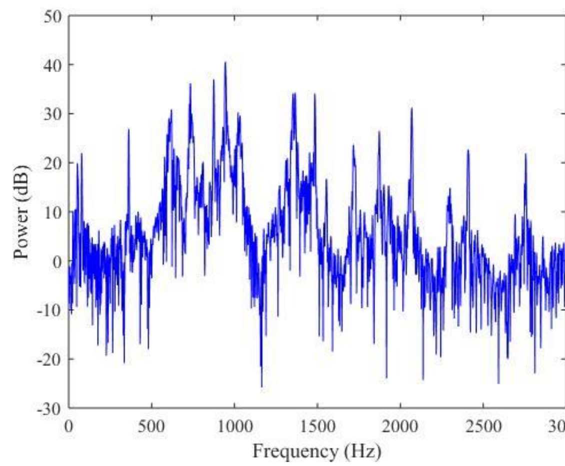

FIGURE 5. Power spectrum of Chenda sample C.

IV. DISCUSSION

The fundamental frequency or pitch is inversely proportional to the number of prominent peaks in the spectra and a pitch up to 200Hz is influenced by harmonics up to fourth and fifth [14, 15]. Thus, first five peaks are considered to study about the harmonicity of the drums.

TABLE III. The frequency ratio of the first five peaks of the strokes of the drums.

Peak Number	*M*	*C*
1	1.09	1.00
2	2.00	1.57
3	3.01	2.18
4	4.00	2.54
5	5.05	2.91

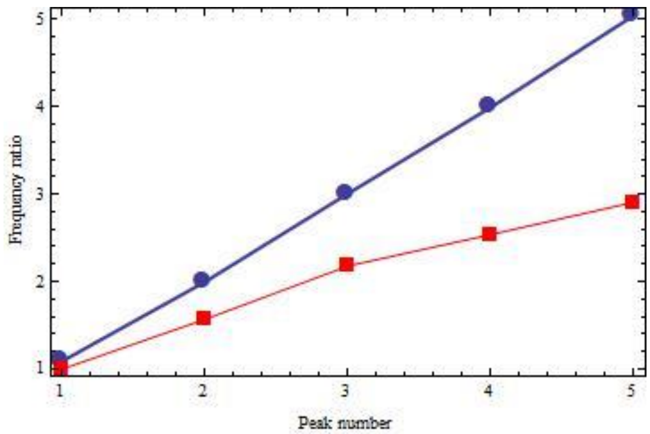

FIGURE 6. Plot of peak number versus frequency ratio for Mridangam and Chenda.

The ratios given in the Table III clearly show integer relation of the harmonics in Mridangam. A comparison of number of peaks and ratios of Mridangam and Chenda is given in Fig. 6. A straight line graph is obtained for Mridangam. The frequency ratio indicates that for Chenda, the strokes do not form peaks with integer relation. Why this happens? In Mridangam accurate pitch is produced by the application of central loading on the drum head that shifts the modes of the membrane to harmonic frequencies.

In Chenda, there are no such mechanism and hence the modes vibrates in frequencies which are not related in an integer multiple form.

VI. CONCLUSIONS

The sound produced by drum Mridangam is musical to hear due to the presence of high amount of harmonics. Chenda does not produce musical sound with definite pitch as there is lack of harmonically related overtones. Suitable changes in the stretching of the drum head by addition of loading at the middle region of the drum head creates modes that vibrate at frequencies that are integer multiple of the lowest frequency and increases the harmonicity of the sound produced by the Mridangam. This work we hope will help the undergraduates, to understand about the importance of the frequency ratio and their alignment in integer order for producing pitched sound.

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