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Drum cavity excitation induced membrane percussion of the Indian folk instrument *Sambal*

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Abstract - The Indian percussion instruments family, in its folk category, has many instruments like *Dholki, Dimdi, Duff, Sambal etc*. The *Sambal* is a folk membranophone popular in western India and is made up of metal, wood, animal skin and rope. The *Sambal* is a traditional drum that is used in a number of religious functions. It is generally played by people who are believed to be servants of the goddess Mahalaxmi Devi. This instrument is made up of a pair of metal or wooden pots with animal skin membranes stretched over their open ends. The *Sambal* is played using a pair of wooden sticks, one of which is curved beyond the shaft form shoulder to tip. The pitch of the right hand side drum that is struck with this specially modified stick is higher than that of the left. Each membrane is excited by repeated strikes generating sounds of constant pitch. This paper discusses vibrational analysis of the *Sambal*. A spectral analysis of sound picked up in the near field and the modes of membrane-vibration are presented. The investigation has been carried out by employing i) A DSO that provides an FFT of the tone that is picked up in the near field using a condenser microphone, and ii) A horn driver that excites the drum cavity, stimulating the membrane indirectly.

Index Terms- Sambal, Percussion, cavity modes, vibrational analysis, spectral analysis, horn driver, FFT

1 INTRODUCTION

The instrument under study is the folk instrument *Sambal [1]* that belongs to the membranophone category. The Sambal is made up of two cylindrical pots of wood, or metal. The *Sambal* under investigation is made up of wood and commonly played in religious ceremonies in western India. The cylinders are tapered and closed at one end and have animal skin membranes pulled over the other (Fig. 1). The pots are generally held close to each other by some temporary mechanism for the convenience of the drummer. The membranes are excited by striking repeatedly to generate sounds of constant pitch.

Fig. 1. The *Sambal*

The right and left hand drums called *Dhum* or *Chap* are both carved out of wood. The *Sambal is* played using a pair of sticks out of which one is bent at the shaft from shoulder to tip. The bent stick is used to play the right hand drum whereas a regular stick is used to play the left. The right side membrane has a black coating made up of wax similar to a *Tabla (syahi) [2]*. However, unlike the *Tabla*, the coating viz. *syahi* is on the underside of the membrane and solely helps in raising pitch. The right hand drum is used for the treble-effect whereas the left is used for the bass. In the course of our investigation, the membranes have been excited directly by striking and also indirectly by exciting the hollow drum cavity employing a horn driver.

2 DIRECT EXCITATION SPECTRAL ANALYSIS

A simple arrangement as shown in Fig. 2 was used to investigate the percussion characteristics of the *Sambal*. As there are no specific syllable / *bols [2]* to be played like other percussion instruments viz. *Tabla [2]* or *Pakhawaj [6]*, the instrument was studied by striking the membranes independently first and later both left and right membranes together. The pressure response was picked up using an omnidirectional condenser microphone (Ahuja CTP-10DX) in the near-direct field of the *Sambal*. The microphone was connected to a 40 MHz 2-channel digital storage oscilloscope (Aplab D-36040C) and an FFT (Fast Fourier Transform) was obtained for each of the cases. The FFT being an efficient mathematical algorithm that derives the frequency domain signal from time domain is used to investigate the percussion characteristics.

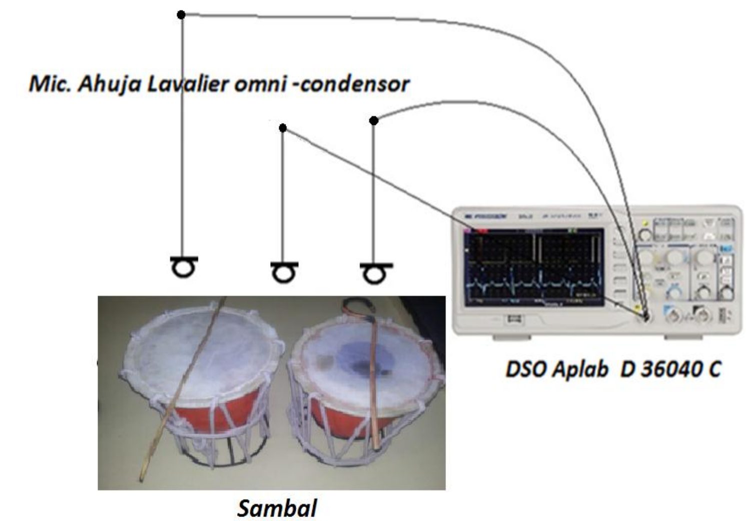

Fig. 2. Experimental setup for spectral analysis

3 INDIRECT EXCITATION MODAL ANALYSIS

The *Sambal* drum-cavity was excited by using an Ahuja AU-60 horn driver unit (Fig. 3). The horn driver was driven by an amplifier Ahuja TZA-1200 in conjunction with an audio frequency oscillator Equiptronix EQ-206. Holes, 1.5 inch in diameter, were drilled in the solid wooden base of the drum to fit the horn driver (Fig. 4). The oscillator frequency was varied and modes of vibration[3] obtained. Fig. 5 shows one such mode of vibration (0, 2) wherein the stained sawdust, sprinkled over the membrane, has accumulated along boundaries distinctly exposing the vibration mode. The complete experimental arrangement is shown in Fig. 6.

Fig. 3. AU-60 Horn driver unit

Fig. 4. Holes drilled in the wooden base to accommodate the driver

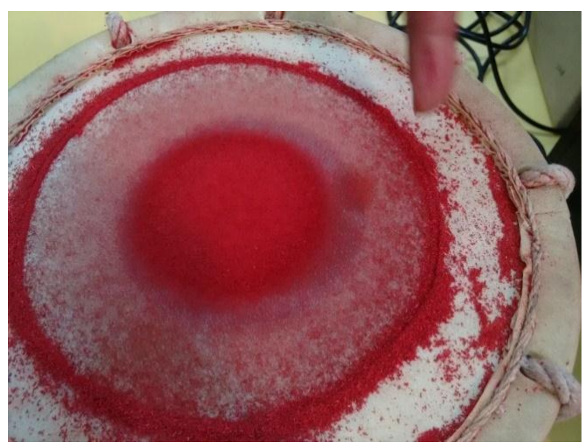

Fig. 5. Mode (0, 2): Stained sawdust accumulating around boundaries

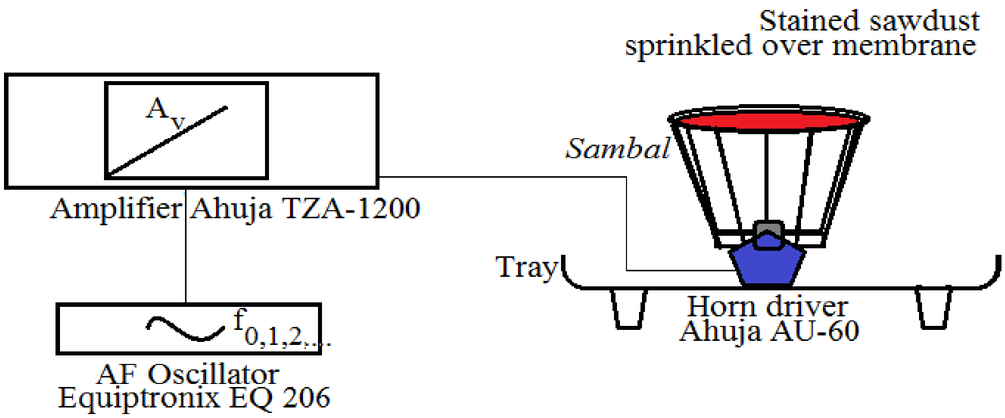

Fig. 6. Experimental setup for modal analysis

4 BACKGROUND

Nobel laureate Prof. C. V. Raman and his colleagues carried out a scientific study of various Indian drums like *Pakhawaj, Tabla, Mridangam*, etc. They highlighted the unique feature in Indian drums viz. the loaded membrane. The loading is brought about by an adhesive- called *syahi* which is a finely ground powder of Psilomelene – a stone found in Bhavnagar region of the state of Gujrat in India and boiled thick paste of refined wheat flour. Psilomelene is also known as Black Hematite which is a group name for hard black manganese oxides such as Hollandite and Romanechite [2]. The *syahi* helps in uplifting the overtones of Indian drums into harmonics. Prof. C. V. Raman and his team recognized that the first four overtones of the *Tabla* were harmonics of the fundamental [3]. The patterns published by Raman in 1934 were skillfully obtained by sprinkling fine sand on the membrane before or immediately after the stroke. The sand gathered along the nodes which were the lines of least amplitude – forming a map of the vibration pattern excited by the stroke. It was later argued by Thomos D. Rossing [4], that it would rather be easier to excite these modes by driving the membrane at the right frequency with an audio amplifier and a suitably placed loudspeaker. Nonetheless, those instruments were not readily available to Raman in 1934.

5 SYMMETRICAL FREE VIBRATIONS OF CIRCULAR MEMBRANES

Vibrational modes for a circular membrane are obtained using Bessel functions [5]. Their forms and frequency ratios are derived from the wave equation for a stretched membrane in which the transverse displacement at a point is expressed as

$$y = y(x, z, t) \qquad (1)$$

In setting up the equation of motion for a rectangular element of area $dS = dxdz$, the membrane is assumed to be perfectly elastic, thin, uniform and having negligible stiffness, with no damping and vibrating with small displacement amplitudes. The tension T will be distributed uniformly throughout the membrane, so that the material on opposite sides of a line segment of length dS will tend to be pulled apart with a force of TdS.

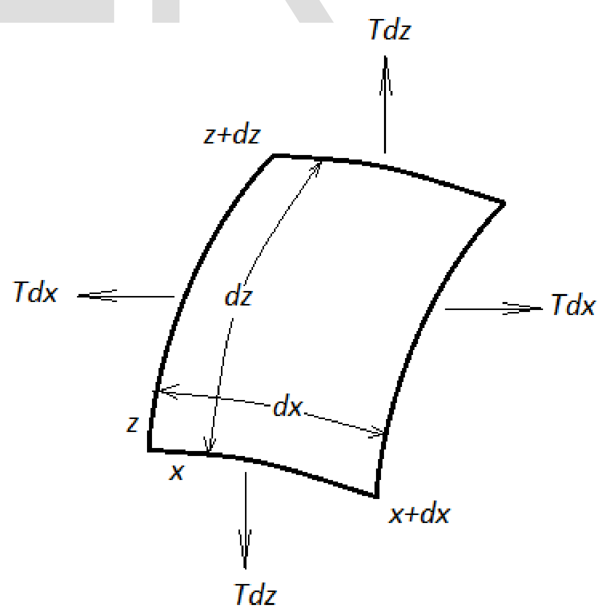

Fig. 7. Force acting away from the equilibrium plane of a membrane element

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To find an expression for the restoring force acting on any such element of the membrane described above (Fig. 7) that bulges away from the equilibrium plane, by argument analogous to that used for the transverse force acting on a segment of the string, the net force on the element *dxdz* due to the pair of tensions *Tdz* is

$$Tdz\left[\left(\frac{\partial y}{\partial x}\right)_{x+dx}-\left(\frac{\partial y}{\partial x}\right)_{x}\right]=T\frac{\partial^2 y}{\partial x^2}dxdz$$

And that due to the pair of tensions *Tdx* is

$$T\,\frac{\partial^2 y}{\partial Z^2}dxdz$$

Equating the sum of these two terms to the product of the element's mass *σdxdz* and its acceleration $\frac{\partial^2 y}{\partial t^2}$, we would have

$$T\,\left(\frac{\partial^2 y}{\partial x^2}+\frac{\partial^2 y}{\partial z^2}\right)dxdz=\sigma dxdz\frac{\partial^2 y}{\partial t^2}, \text{ or}$$

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

$$\text{where } c=\sqrt{\frac{T}{\sigma}} \qquad (3)$$

For a circular membrane having a fixed boundary of radius a, it is necessary to express the Laplacian operator in polar coordinates r and θ, where $x = r\cos\theta$ and $z = r\sin\theta$. Differentiating r and θ partially while regarding these as implicit functions of x and z, the Laplacian in polar coordinates turns out to be

$$\nabla^2=\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{1}{\partial r}+\frac{1}{r^2}\frac{\partial^2}{\partial\theta^2} \qquad (4)$$

A substitution of this relationship into equation (2) leads to

$$\frac{\partial^2 y}{\partial t^2}=c^2\left(\frac{\partial^2 y}{\partial r^2}+\frac{1}{r}\frac{dy}{dr}+\frac{1}{r^2}\frac{\partial^2 y}{\partial\theta^2}\right) \qquad (5)$$

Eqn. (5) is the most general wave equation appropriate for discussing transverse vibrations of a circular membrane. In almost all cases of practical importance in acoustics, the membrane vibrates with circular symmetry i.e. $y = y(r, t)$ alone, and is independent of the azimuthal coordinate θ. In this case, equation (5) simplifies to

$$\frac{\partial^2 y}{\partial t^2}=c^2\left(\frac{\partial^2 y}{\partial r^2}+\frac{1}{r}\frac{dy}{dr}\right) \qquad (6)$$

As with the transverse vibrations of a bar, the solution of equation (6) can most readily be obtained by assuming that the displacement may be expressed as the product of separable time and space dependent terms. Thus, for harmonic vibrations, let us assume that

$$y=\psi e^{j\omega t} \qquad (7)$$

Where $\psi = \psi(r)$ is a function of r alone and not a function of the time t. A substitution of equation (7) into equation (6) reduces the latter equation to

$$\frac{\partial^2\psi}{\partial r^2}+\frac{1}{r}\frac{d\psi}{dr}+k^2\psi=0 \qquad (8)$$

$$\text{where } k^2=\frac{\omega^2}{c^2}=\frac{\sigma\omega^2}{T} \qquad (9)$$

Equation (8) can be solved by assuming a series solution of the form

$$\psi=f(x)=a_0+a_1 r+a_2 r^2+a_3 r^3+a_4 r^4+\ldots\ldots \qquad (10)$$

Then

$$\frac{1}{r}\frac{d\psi}{dr}=\frac{a_1}{r}+2a_2+3a_3 r+4a_4 r^2+\ldots\ldots\ldots\ldots\ldots\text{and}$$

$$\frac{\partial^2\psi}{\partial r^2}=2a_2+3.2a_3 r+4.3a_4 r^2+\ldots\ldots\ldots\ldots\ldots$$

After substituting these expressions into equation (8) we obtain

$$\frac{a_1}{r}+(2a_2+2a_2+k^2a_0)+(3.2\,a_3+3\,a_3+k^2a_1)r+(4.3a_4+4a_4+k^2a_2)r^2+\cdots=0 \qquad (11)$$

Since this summation must be zero for all values of r, each coefficient multiplying a particular power of r must be zero, and hence $a_1 = 0$ and $9a_3 + k^2 a_1 = 0$ (4)

So that a_3=0. Similarly, all the remaining odd-numbered constants, a_5, a_7, etc., may be shown to equal zero. However, in considering the even-numbered constants we see that

$$2^2a_2+k^2a_0=0, \text{ so that } a_2=-k^2\frac{a_0}{2^2} \text{ and } 4^2a_4+k^2a_2=0$$

$$\text{so that } a_4=-k^2\frac{a_2}{4^2}=\frac{k^4a_0}{2^2.\,4^2} \text{ similarly } a_6=-\frac{k^6a_0}{2^2.\,4^2.\,6^2}, etc.$$

Hence the series solution of equation (10) is

$$\psi=a_0\left[1-\frac{(kr)^2}{2^2}+\frac{(kr)^4}{2^2.4^2}-\frac{(kr)^6}{2^2.4^2.6^2}+\ldots\ldots\ldots\ldots\right] \qquad (12)$$

The series included in brackets is the well-known Bessel function of the first kind and of zero order, which is customarily written as $J_0(kr)$. Values of the J_0 function are given below:

TABLE 1

BESSEL FUNCTIONS OF THE FIRST KIND $J_m(j_{mn}) = 0$

	J_{mn}					
m\n	**0**	**1**	**2**	**3**	**4**	**5**
0	---	2.40	5.52	8.65	11.79	14.93
1	0	3.83	7.02	10.17	13.32	16.47
2	0	5.14	8.42	11.62	14.80	17.96
3	0	6.38	9.76	13.02	16.22	19.41
4	0	7.59	11.06	14.37	17.62	20.83
5	0	8.77	12.34	15.70	18.98	22.22

The standard designation of the modes is in the form (m, n) where m represents the number of nodal diameters while n represents the number of nodal circles. From the Table 1 it is clear that the fundamental is from the (0, 1) mode, the second harmonic is from (1, 1) mode, the (2, 1) and (0, 2) modes provide the third harmonic. The (3, 1) and (1, 2) similarly supply the fourth harmonic and the three modes (4, 1), (0, 3), and (2, 2) contribute to the fifth harmonic.

6 RESULTS AND DISCUSSION

6.1 Spectral analysis (Direct excitation) using Fast Fourier Transform

Table 2 comprises prominent percussion frequencies for each of the membranes when struck independently and also when struck together. Figure 8 shows the corresponding decay amplitudes and FFTs. The FFTs show the very first pair of prominent peaks at 240 Hz for the right and 565 Hz for left membrane respectively. A frequency of 300 Hz is seen when both the membranes are struck simultaneously. The combination frequencies are of interest as the professional percussionist often strikes both membranes simultaneously. Overtones at 850 Hz and 1400 Hz are seen in addition when the left hand membrane is struck whereas frequencies like 75 Hz, 450 Hz and 950 Hz surface when both membranes are struck simultaneously.

TABLE 2

FUNDAMENTAL FREQUENCIES OBTAINED BY STRIKING (SPECTRAL ANALYSIS)

Drum side	Frequencies (Hz)
Right side membrane	240
Left side membrane	565, 850, 1400
Combined (Both together)	75, 300, 450, 900

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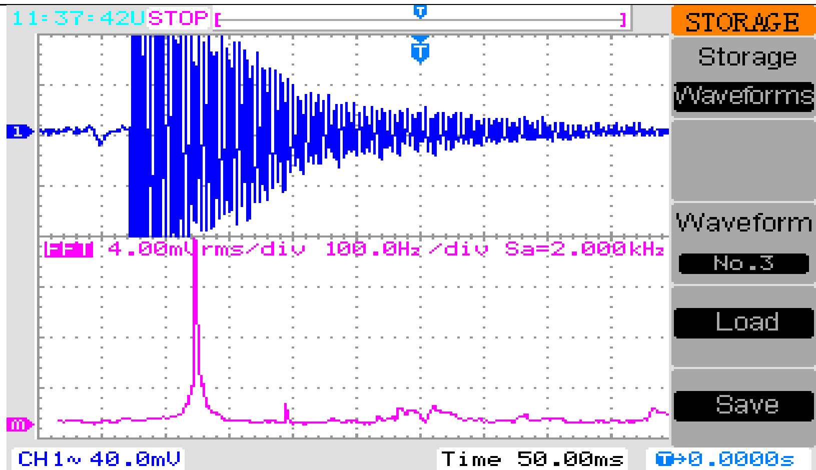
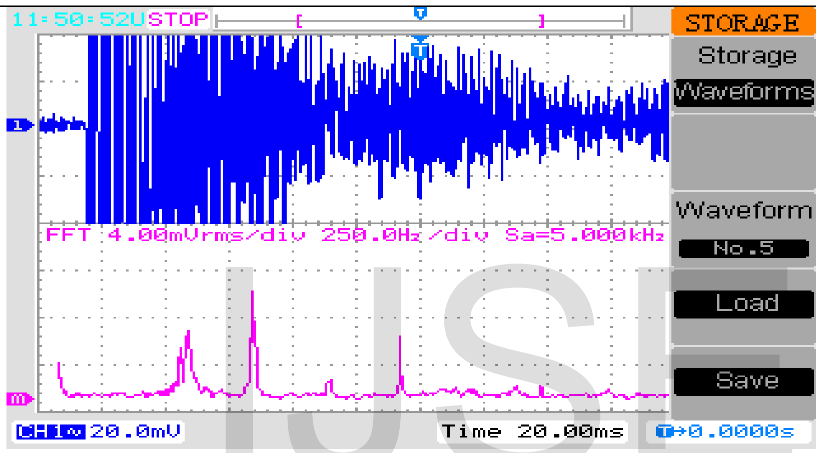
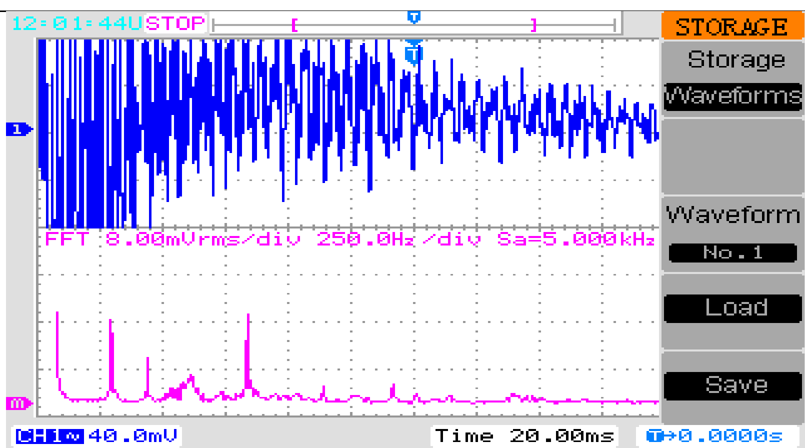


Right hand membrane



Left hand membrane



Combined membrane

Fig. 8. Exponential decay and FFTs for membranes struck independently and at the same time

6.2 Concurrent modal and spectral analysis (Indirect excitation): Fast Fourier Transform for modes

Fig. 9(a) and 9(b) show the setup wherein the two analyses viz. modal and spectral are done concurrently. For modal analysis by indirect excitation the membrane-vibration is photographed using a 15.5Mpx:1920 x1080 cellphone camera, while a

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condenser microphone Ahuja CTP-10DX held in the near-direct field of the vibrating membrane picks up the signal simultaneously. Fine sawdust is sprinkled on the membrane so that the modal patterns are distinctly visible. The sawdust is stained red for a better contrast. The FFT of the pickup signal is obtained using the DSO Aplab D-36040C

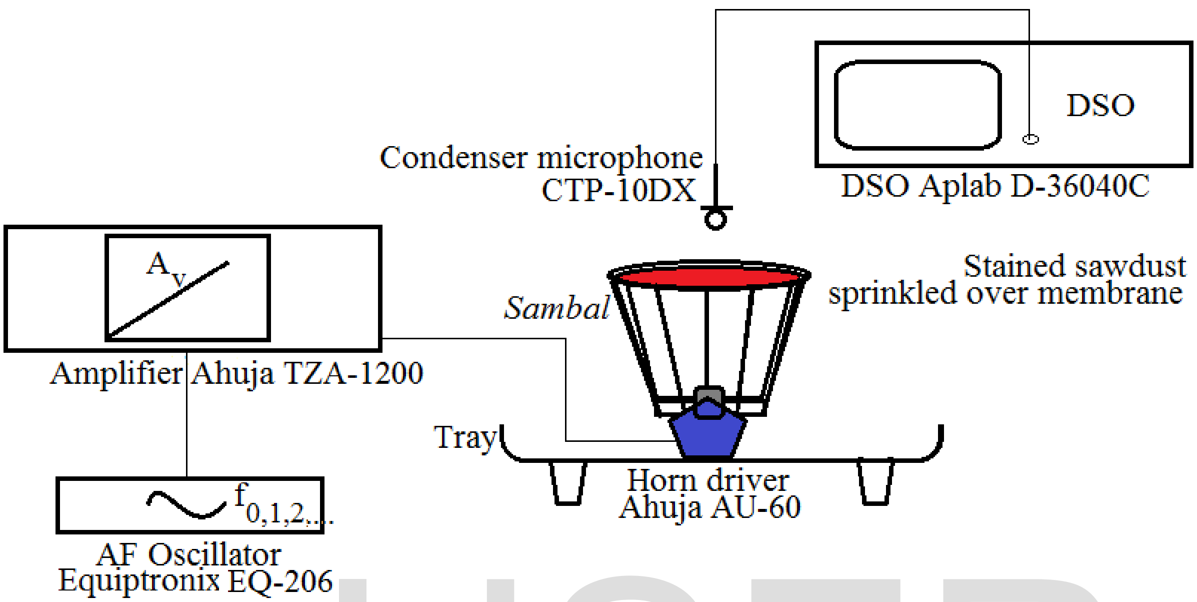

Fig. 9(a). Setup for concurrent modal and spectral analysis by indirect excitation

Fig. 9(b). Photograph of the setup for concurrent modal and spectral analysis by indirect excitation

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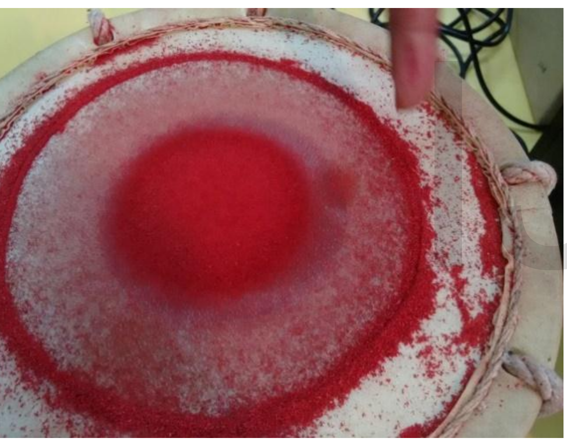
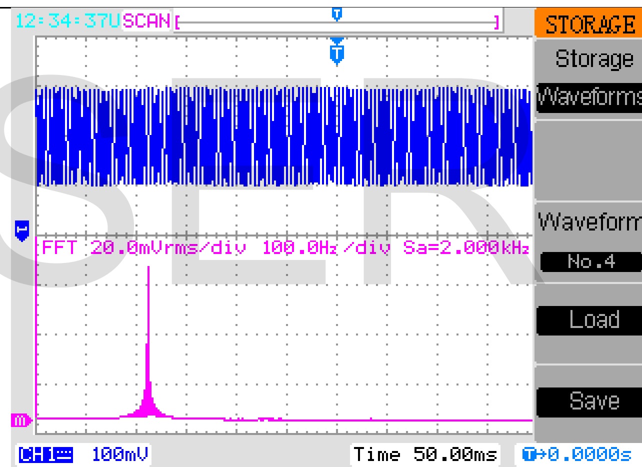
Table 3 lists out experimentally obtained vibrational mode frequencies and their theoretically calculated corresponding values using Bessel functions. The calculated frequencies are in clear agreement with the ones obtained experimentally. Fig. 10 shows photos of actual vibration modes obtained by exciting the membrane indirectly i.e. by exciting the drum cavity and sweeping through various frequency ranges. The photos of the vibration modes and the corresponding FFTs are shown side by side. The FFTs have been simultaneously obtained by picking up the signal using the condenser microphone in the near-direct field of the vibrating membrane.

TABLE 3

VIBRATIONAL MODE FREQUENCIES OBTAINED BY CAVITY MODE EXCITATION

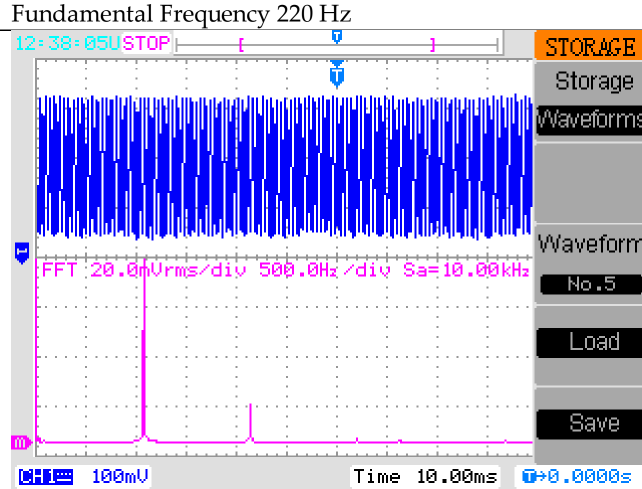
Sr. No.	**Vibrational Mode**	**Frequency (Experimental) Hz**	**Frequency (Bessel) Hz**
1.	(0, 1)	96	100
2.	(0, 2)	220	230
3.	(0, 3)	1056	360
4.	(0, 4)	1390	491
5.	(0, 5)	1595	622





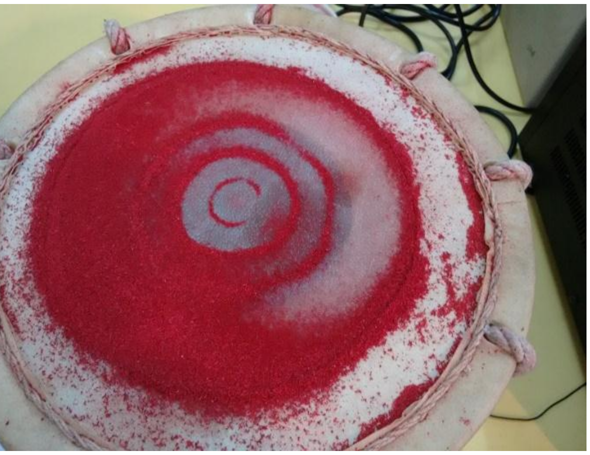
Mode (0, 2)

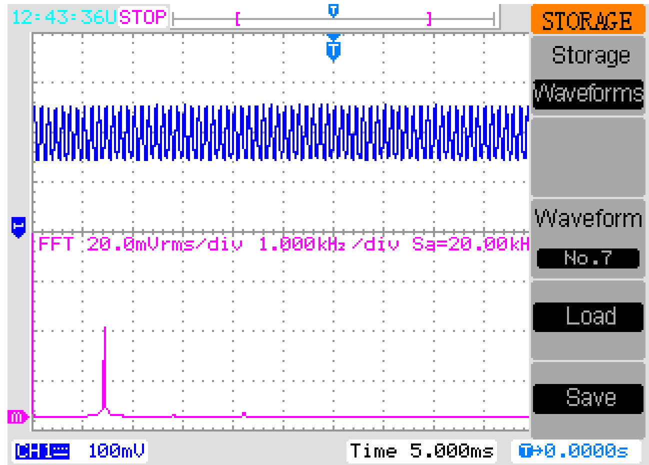
Fundamental Frequency 220 Hz



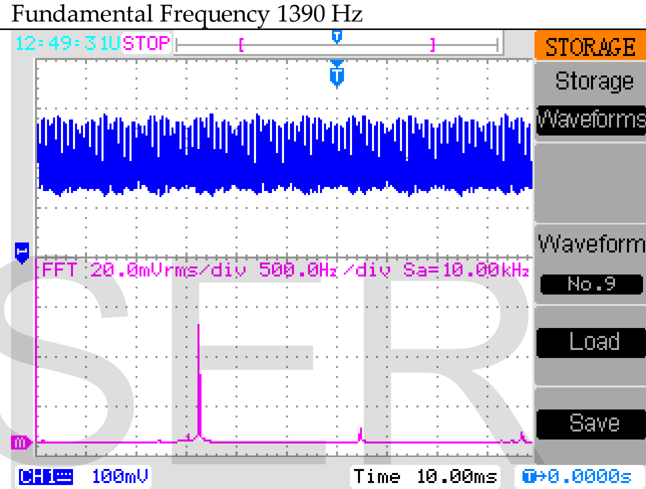
Mode (0, 3)

Fundamental Frequency 1056 Hz





Mode (0, 4)	Fundamental Frequency 1390 Hz



Mode (0, 5)	Fundamental Frequency 1595 Hz

Fig. 10. Vibrational mode frequency photos and corresponding FFTs obtained simultaneously

Table 4. lists the frequency ratios for vibrational modes obtained experimentally by the indirect method using drum-cavity excitation. The ratios agree with the modal vibration ratios obtained using Bessel function: If the mode (0, 1) is assumed to appear as a 100 Hz fundamental, then the mode (0, 2) would be at 230 Hz, (0, 3) at 360 Hz, (0, 4) at 491 Hz, and the mode (0, 5) at 622 Hz. The modal frequency ratios viz. (0, n) / (0, n-1) have been listed alongside in column 3. The corresponding ratios for the experimentally obtained frequencies are listed in column 6. It is evident that all the ratios, except for the ratio (0, 3) / (0, 2), agree with the modal vibration ratios obtained using Bessel function. This single disagreement seems to arise as a consequence of the limited isotropicity affecting membrane stiffness.

TABLE 4

MODES OF VIBRATION AND FREQUENCY RATIOS-A COMPARISION WITH THEORETICALLY CALCULATED VALUES (100 HZ BEING USED AS FUNDAMENTAL FOR BESSEL CALCULATIONS

As per Bessel Function theory			Experimentally obtained values		
Modes of Vibration	**Frequency (Hz)**	**Ratio**	**Modes of vibration**	**Frequency (Hz)**	**Ratio**
(0,2)/ (0,1)	230/100	2.3	(0,2)/ (0,1)	220/ 96	2.29
(0,3)/ (0,2)	360/230	1.56	(0,3)/ (0,2)	1056/220	4.8
(0,4)/ (0,3)	491/360	1.36	(0,4)/ (0,3)	1390/1056	1.31
(0,5)/ (0,4)	622/491	1.26	(0,5)/ (0,4)	1595/1390	1.14

A comparison of the *Sambal* with the *Tabla [2]* and the *Pakhawaj* [6] shows that the Bessel function fits well even in case of membranes for which loading is underneath the membrane and slightly displaced from the center, as in the case of *Sambal.* Spectral analysis shows that not all vibration modes, when the membrane is struck (as during normal playing), are identical to the vibration modes obtained when the membrane is excited indirectly.

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