THE INDIAN MUSICAL DRUMS.

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1. Introduction.

Many years ago,[1] I drew attention to the remarkable acoustic properties of the musical drums which are used as accompaniments to vocal or instrumental music and are extremely popular in India even at the present time. My investigations showed clearly that these instruments contained the solution in a practical form of the acoustical problem of transforming a circular drum-head giving inharmonic overtones into a harmonic musical instrument. In its classical form, the instrument is known as the Mridanga, and is referred to in ancient Sanskrit works and is also pictured in the paintings on the walls of the Ajanta caves. It is thus clearly a very ancient invention, and its acoustical perfection must be considered a remarkable testimony to the inventiveness and musical taste of its progenitors. The physical study of the Mridanga, however, possesses more than a merely archæological interest. As was pointed out in my earliest note on the subject and somewhat more fully in my article[2] on musical instruments in *Handbuch der Physik.*, the successful conversion of an inharmonic sequence of tones into a harmonic one has been effected in a very interesting manner. The drum has the special property of vibrating freely in different forms but with identical frequencies which can be superposed on each other. Some of the superposition forms have a striking simplicity, and indicate an analogy between the musical drum and the harmonic vibrations of a uniform stretched string. In view of the extreme brevity of the accounts previously published, it appeared desirable to set out more fully the results obtained. The subject is, however, far from being exhausted by the present report, and it is hoped that the paper is only the precursor of a complete treatise on the musical drums of India.

2. Description of the Instruments.

An immense variety of drums of various forms and shapes are to be found in use in different parts of the country. The musical drum, however, stands apart in a class by itself, and is used exclusively for high class

[1] C. V. Raman, *Nature*, 1920, **500**, 104.
[2] *Handbuch der Physik. Akustik*, 1927, **8**, 414.

chamber music where the noise of an ordinary percussion instrument would be intolerable. The classical form of the instrument known as the Mridanga is a two-sided drum which is played with both hands. Its shape resembles that of two truncated cones or flower-pots placed together end to end with the narrow ends outwards. The construction usually takes the form of a hollow wooden shell of the shape mentioned with both ends open over which the drum-skins are stretched. To enable the drum-skins to be tightened to any desired tension, and at the same time ensure a uniform tension in all directions, the following device is adopted. The drum-heads are firmly attached to circular hoops by interlaced thongs of leather. The hoops are then put over the ends of the drum. A long band of leather repeatedly passes through both the hoops and to and fro over the full length of the drum, in all exactly sixteen times at equal intervals along its circumference. The ends of the leather band are then tied together. The tuning of the drum is roughly effected by lightening up the leather cord by adjusting the position of 8 movable cylindrical blocks of wood over which it passes. The final adjustment is made by the strokes of a hammer which force down the hoop over which the drum-head is stretched to the extent desired. The arrangement enables the drum-head to be accurately adjusted to any desired tension, and, what is equally important, enables the tensions in different directions to be equalised with meticulous precision. One can travel from one end of India to the other and seek in vain for a Mridanga which has either more or less than sixteen tightening straps. It is clear, therefore, that the inventors of the drum not only realised the importance of equalising the tensions, but laid stress on having exactly the right number of tension equalisers, namely, sixteen.

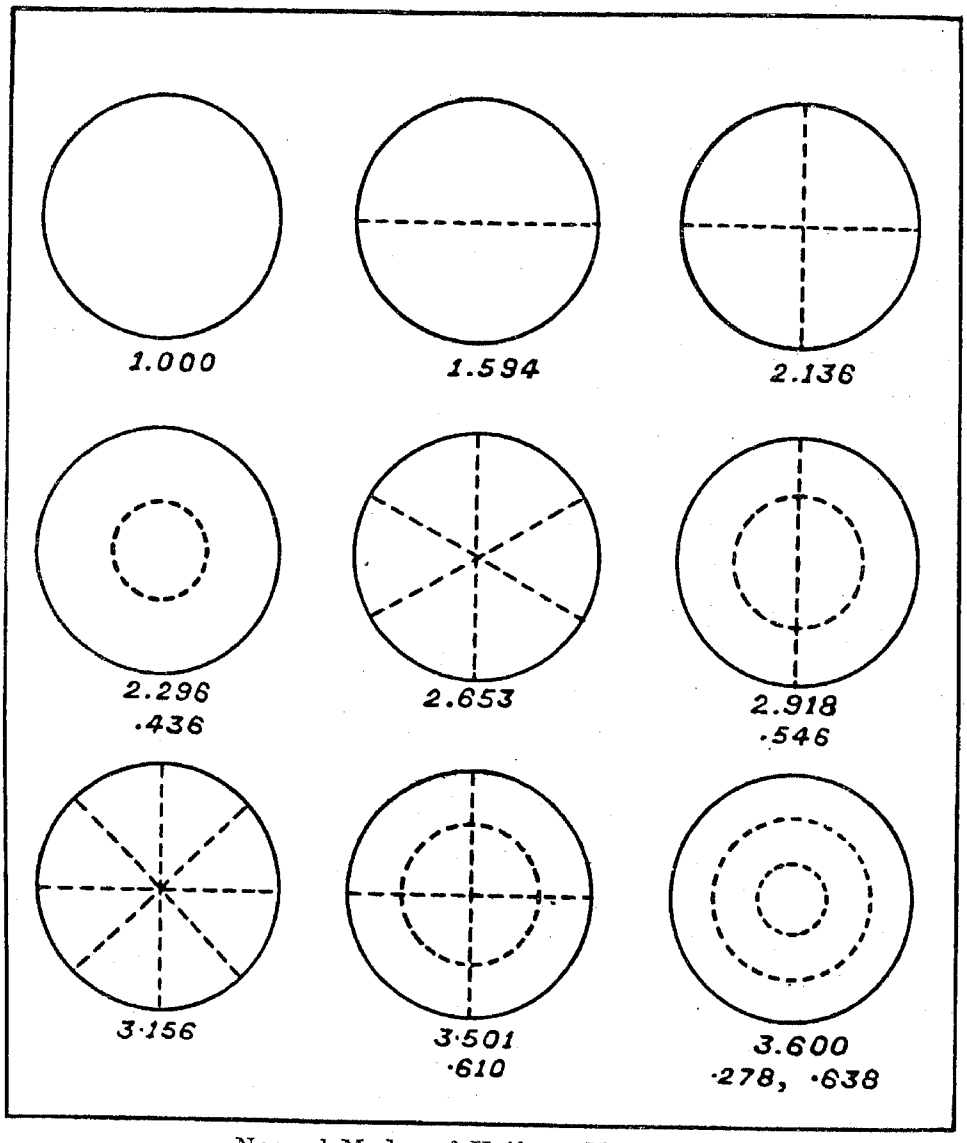
Apart from the details mentioned above, the special feature of the Mridanga consists in the construction of the drum-head played with the right hand. As originally put on, the drum-head is not a single piece of leather, but consists of three layers of drum-skin superposed on each other. In the final stages of construction, all the layers except one are taken out leaving only rings round the margin to reinforce one drum-skin which is left intact and is capable of vibration. Externally one such ring of leather is visible over the drum-head. The latter is then loaded symmetrically with a firmly adherent composition which is said to consist of finally divided iron-oxide mixed with charcoal, starch and gum. The laying on of this composition and making it firmly adherent are elaborate processes which take a great deal of time. Actually, the composition is put on layer by layer and pressed down by rubbing with a smooth piece of stone or metal. The thickness of the layer is greatest in the centre and shades down

towards the margin. In some cases, it is found that the thickness is stepped down by three, five or seven stages towards the margin. Watching the process of putting it on, it is found that the thickness and distribution are determined by testing the tone of the drum continuously as the work proceeds.

The left-hand drum-head of the Mridanga is usually larger in size than the right-hand one. It is constructed in a similar manner to that described above, but without the central loading. In playing the instrument, however, the left-hand drum-skin is loaded with a piece of dough (kneaded wheat-flour) which is moistened and put on in sufficient quantity towards the centre to bring the pitch down to the desired value.

A modern variant of the Mridanga is known as the Thabla. This really consists of two drums placed simultaneously with the right-hand and left-hand respectively. Both consist of wooden or metal shells open at one end only and covered with drum-skins. The drum-head of the Thabla played with the right-hand is very similar to that of the Mridanga. The drum played with the left-hand has a firmly adherent composition which is, however, unsymmetrically placed on the membrane. The purpose of such unsymmetrical loading is quite different from that of the symmetrical loading used in the right-hand drum, with which alone we are concerned in the present paper. The tension arrangements in the Thabla are similar to those in the Mridanga, with the difference that the tightening cords simply pass round the closed end of the Thabla. The number of tightening straps is exactly 16 as in the Mridanga. In some very recent forms of Thabla, the tightening is effected by 16 iron rods placed at equal intervals round the drums, each having a hook which goes over the circular hoop of the drum-skin and is provided with a tightening nut and bolt at the lower end. With this arrangement again it is possible to adjust the tensions very accurately to equality in all directions.

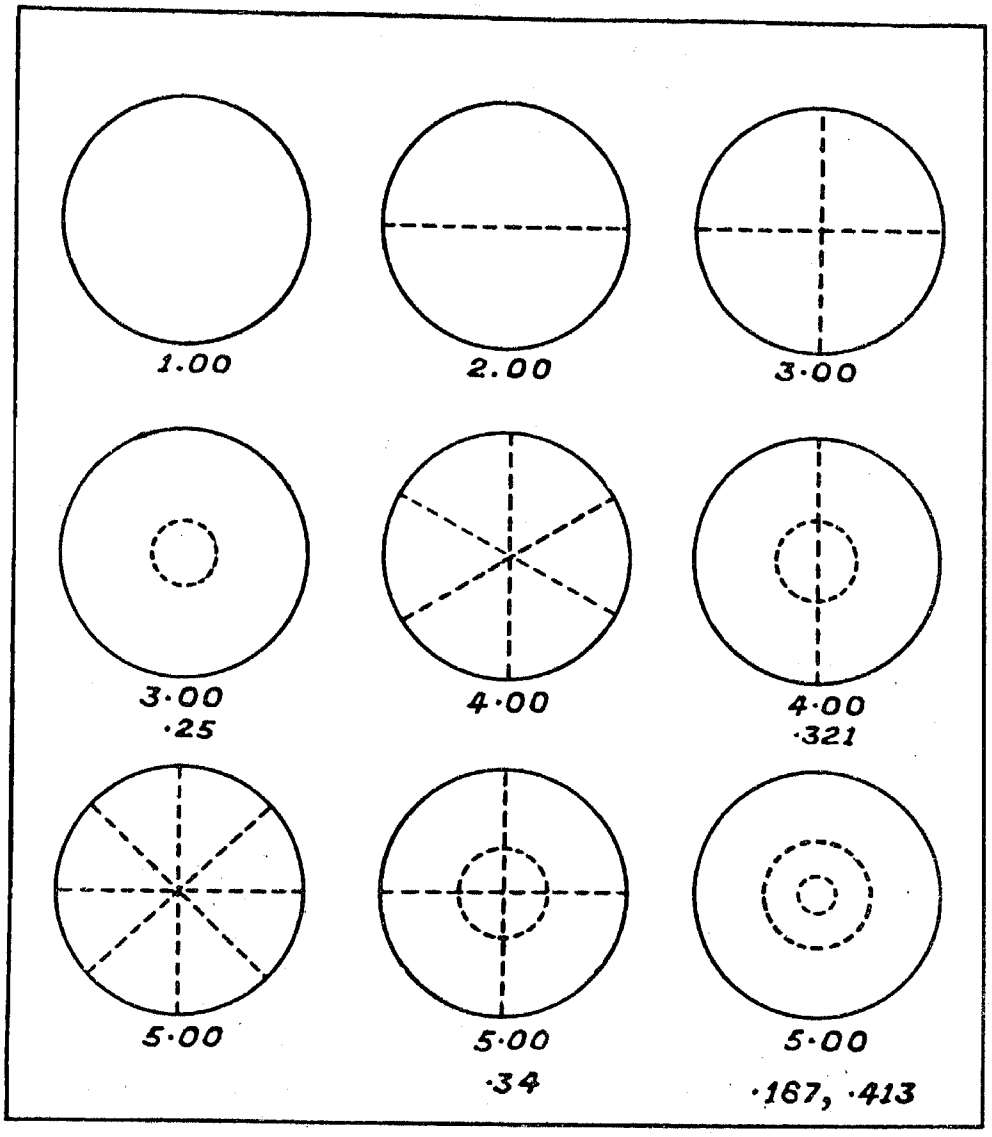
The description of the Mridanga and of the Thabla given above is sufficiently comprehensive to cover all cases met with in practice. It must not be imagined, however, that all instruments going by these names are exact copies of each other. This is far from being the case. The individual examples differ notably in the size and shape of the wooden shell used, as also in the nature of the wood itself and the thickness of the shell. Notable differences also occur in the thickness of the leather used for the drum-skin, in the exact area and distribution of the central load, and specially also in the width of the marginal ring of the leather which is left superposed on the vibrating drum-head. In some forms of Mridanga or Thabla, the marginal ring is left very wide. In others, it is cut down to the barest minimum.



Normal Modes of Uniform Membrane.

3. Its Acoustic Characters.

The most striking feature which distinguishes the Mridanga and the Thabla from other forms of drum is the sustained character of the tones. This is evidently the result of two features in the construction, namely, the heavy wooden shell on which the drum-head is stretched and the symmetrical loading of the latter by a firmly adherent composition. A drum-head which is stretched on a frame of small mass is obviously incapable of prolonged vibration, owing to the rapid communication of movement to the supporting frame. The heavy rigid shell in the Mridanga or Thabla, on the other hand, is favourable to the sustained vibration of the drum-head. The loading of the drum-head greatly increases the energy of vibration and is



Normal Modes of Harmonic Drum.

therefore a factor which favours the emission of a sustained tone. The presence of the enclosed air within the shell is probably also a factor tending in the same direction.

It is empirically observed that the width of the marginal ring of leather superposed on the drum-head has a notable influence on the duration of tone. The ring in fact acts as a kind of damper, and its width is adjusted to obtain the desired kind of tone. With a broad ring, we obtain a muffled tone of short duration in which few overtones are present, while with a narrow ring, the tone is prolonged and is also brighter, containing more overtones. From these observations, it is to be inferred that the purpose served

by the marginal ring is mainly to suppress high tones which are not desired. The mechanism of such suppression is not difficult to understand. It is well known that in the case of a circular drum-head, the amplitude of vibration is relatively greatest towards the centre in the case of lower tones, but increases relatively towards the margin in the case of the higher overtones having several nodal diameters. The leather ring, therefore, acts as a damper for these high overtones without sensibly influencing the lower tones. Too broad a ring, however, carries the suppression to an undesirable extent, cutting out even the tones of lower pitch. As will be seen later in the paper, the construction of the drum-head seeks to arrange the first nine normal modes of the membrane into a harmonic sequence of five tones. The existence of normal modes of still higher pitch can only serve to injure the final result, and their elimination may therefore be described as the purpose of the marginal ring. The latter cannot greatly affect the pitch of the graver tones inasmuch as the amplitude of vibration is rather small for such tones towards the margin, and the effect of the marginal ring considered as a load must therefore be unimportant. The contact between the ring and the drum-head is probably imperfect, and this should tend to make the ring act as a damper rather than as a load influencing the pitch.

It should be mentioned that the Mridanga and Thabla, though they have much in common, are by no means identical in their acoustic properties. In the playing of the Mridanga, the flat of the hand is used more frequently, while with the Thabla, the finger tips are usually employed.

4. The Five Tones of the Drum.

The sustained character of the vibrations of the drum makes it possible to excite and observe them very readily. Indeed, one of the most striking properties of the harmonic drum is that any desired mode of vibration may be excited by simple percussion quite as easily as a stretched string may be caused to vibrate in one or other of its harmonic modes by touching it at a nodal point and plucking it suitably. The analogy is indeed very close as will be presently made clear.

The gravest mode of vibration of the drum-head is, of course, that without any interior nodal lines. This is best excited by bringing down the flat of the palm of the hand smartly on the centre of the drum-head and then quickly removing it. Produced in this way, the deep hum-tone obtained is quite free from overtones, whereas the tone obtained by striking the drum with the finger tips contains overtones.

The second tone of the drum-head is that having one nodal diameter. The professional drummer excites this by smartly striking the membrane

with the edge of his palm laying his little finger along a diameter so as to bring it to rest, while the edge strikes the membrane and rapidly recoils from it. A clear sustained tone is obtained in this way. That the membrane thus excited vibrates with one nodal diameter at rest is readily demonstrated by strewing a little fine sand on it either before or immediately after the stroke. The sand gathers itself into a clear-cut straight line along a nodal diameter coinciding with the position of the little finger in striking. For the success of this experiment, one has, of course, to cultivate the professional touch in the manner of striking the drum. It is also very important to adjust the tensions of the membrane in different directions to equality with great care. If this is not done, the experiment succeeds only if the drum is struck along the nodal diameter having the greatest or the least tension. When struck along a diameter with an intermediate tension, beats are heard, and the nodal diameter as indicated by the sand rotates to and fro about the centre periodically. If the beats are very fast, the sand is visible only as a little pile at the centre of the drum-head.

There is another method of exciting the mode of vibration with one nodal diameter which is very simple and does not need any professional skill. This is merely to touch the membrane gently with one finger of the left-hand laid along a diameter near the margin, and to strike the membrane smartly with a finger of the right-hand at a suitable point on the perpendicular diameter. The finger touching the drum determines the position of the nodal diameter which is indicated by the sand forming a line across the drum-head. (See Fig. 4.)

For exciting the third tone of the drum by itself, the simplest method is to touch the membrane gently with the fingers at two points near each other on the edge of the black central load and then strike the drum smartly with the finger at a point removed 90° away ; a clear ringing tone is obtained, and if the two points touched are at a suitable distance apart, two parallel nodal lines stretching across the drum are formed by the sand (Fig. 5). The significance of this form relatively to the usual modes of vibrations of a circular drum-head will be considered later.

The fourth tone of the drum is similarly excited by touching the edge of the loaded area lightly at three points, and striking the drum near its outer edge smartly with the finger at a point 90° away from the middle of the three points touched. If the three points touched are at suitable equal distances apart, the drum-head vibrates with *three* parallel nodal lines stretching across it, the position of which is indicated by the lines of the sand (Fig. 6). A clear ringing tone is heard at the same time.

The fifth tone may similarly be excited by touching the edge of the loaded area at *four* points, and striking the drum smartly at a point some distance away on the marginal ring of leather. Except in large and specially well-made instruments, the duration of this tone is rather small, and it is not quite so easy to obtain its sand figures by percussion as in the case of the graver tones.

The harmonic relationship between the five tones of the drum is readily appreciated when they are excited one after another in the manner described above. It will be noticed that the fundamental corresponds to the drum-head vibrating as a whole. The second harmonic corresponds to the drum-head vibrating in two equal parts separated by a nodal diameter. The third harmonic corresponds to a mode of vibration in which the drum-head divides into *three* parts separated by two parallel nodal lines. The fourth harmonic corresponds to a mode in which the drum-head divides into *four* parts separated by three parallel nodal lines. The fifth harmonic similarly corresponds to a case in which the drum-head vibrates in *five* parts separated by *four* nodal lines. The analogy with the simple case of a vibrating stretched string is thus remarkably close.

5. *Superposition Figures of the Third Harmonic.*

We have now to consider the relationship between the normal modes of vibration of the drum-head and the series of harmonic tones given by it. As regards the first and second harmonics, no special remarks are necessary as the modes of vibration are unique in each case. The third harmonic, on the other hand, is produced by a combination, in any desired ratio of amplitudes, of the modes of vibration of the drum-head with *one nodal circle*, and the mode with *two nodal diameters*. The proof of this statement is very easy and is illustrated in Figs. 7 to 12. It depends on the fact that by touching the drum-head gently at suitable points and exciting it by percussion, the mode of vibration with one nodal circle, and the mode with two nodal diameters may be excited, either each by itself, or together in any desired ratio of amplitude. In either case, the pitch of the tone obtained is identical, but the superposition gives rise to nodal diagrams which are observed as sand figures and assume varying shapes.

The mode of vibration with one nodal circle is most readily obtained by touching the drum-head at some little distance from its centre with the tip of a pencil, and tapping the centre with a light hammer. If the point of damping has been suitably chosen, a nodal circle is obtained. If it is too near or too far from the centre, an elliptic sand figure is found. To

obtain a very elongated ellipse, we touch two points which are very close to each other on the edge of the loaded area and strike the drum with the finger at a point removed from them by 90°. On increasing the distance between the two points touched, the ellipse straightens out and we obtain two parallel nodal lines running across the drum-head, and dividing it into three parts of which the middle has a smaller area than two outer ones. On further increasing the distance between the two points touched, the nodal lines curve outwards and assume the form of hyperbolæ. Finally, when two points 90° apart on the edge of the loaded area are damped with the fingers and the drum is struck at the mid-point of the adjacent quadrant, we get two nodal diameters passing through the centre.

6. *Superposition Figures of the Fourth Harmonic.*

The fourth harmonic is given by the drum-head vibrating in one or other of two forms: (*a*) a mode with one nodal diameter and one nodal circle, (*b*) a mode with three nodal diameters, or by superposition of both these forms. This is demonstrated by the sand figures reproduced as Figs. 13–18. Most of the figures for the fourth harmonic are obtained by touching three points on the edge of the loaded area and tapping the drum with the finger just on the inner edge of the marginal ring of leather. If the three points touched are exactly 60° apart from each other, we get the mode of vibration with three nodal diameters. If they are closer together but at equal distances the diagram takes the form of three lines, one of which is a diameter running across the drum-head and the other two are hyperbolæ curved outwards. As a special case, we have the figure consisting of three parallel straight lines running across the drum. All these figures are evidently obtained by the superposition of the normal two modes mentioned above. To obtain by itself the mode with one nodal diameter and a nodal circle, the device is adopted of touching the loaded area at two points 90° apart, one at the edge of the loaded area and the other on the nodal circle itself and of tapping the drum-head near its edge.

A specially interesting case is that shown in Fig. 18 where we have a nodal figure consisting of three lines, two of them running perpendicular to the third which is a diameter. This is really the same case as that of three parallel lines running across the drum-head and may be derived from it by reversing the relative phase of the two superposed modes of vibration. It is obtained by touching the edge of the loaded area at three points, one of which is removed by 90° from the mid-point of the other two. In general, when the three points touched are unequally spaced, we get curious curved nodal lines of which Fig. 17 is an example. These are

clearly due to superposition of the two normal modes with the nodal diameters not coincident but inclined to each other.

7. *Superposition Figures of the Fifth Harmonic.*

From the fact that the fifth harmonic is obtained when four points on the drum-head are damped, it may be inferred that it arises from a superposition of at least two modes, namely, (*a*) one with four nodal diameters only, (*b*) one with two nodal diameters and a nodal circle. Experiments made at Calcutta in 1919 with a fine large Mridanga showed that in reality we have also a third mode superposed on the above, namely, the mode with two nodal circles only. By touching the drum at suitable points, it was found possible to excite any of the foregoing three modes by itself, and obtain the relative sand figures, the pitch of the modes being the same in all the three cases. If it is possible to excite the drum in sustained vibrations of this frequency, a great variety of superposition figures should evidently be capable of being obtained.

8. *Summary.*

The paper gives a detailed description of the results obtained by the author in the year 1919 which showed that in the Indian musical drums we have a circular drum-head which is loaded and damped in such a manner that all the overtones above the ninth are suppressed and these nine are grouped in such a manner as to give a succession of five tones in harmonic sequence. The vibrations of the drum-head present a striking analogy to the case of a stretched string giving one or the other of its first five harmonics ; the drum-head divides up into 1, 2, 3, 4 or 5 sections giving the respective harmonics. The third, fourth and fifth harmonics are obtained by superposition of 2, 2 and 3 respectively of the normal modes of vibration. The corresponding superposed forms of vibration are readily obtained and demonstrated by means of sand figures. Numerous figures illustrate the paper.

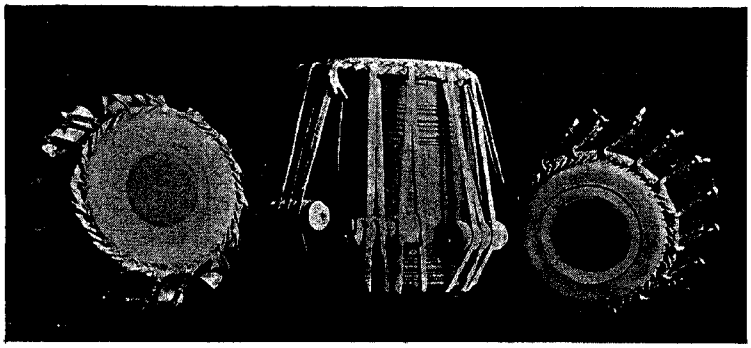


FIG. 1. A Group of Thablas.

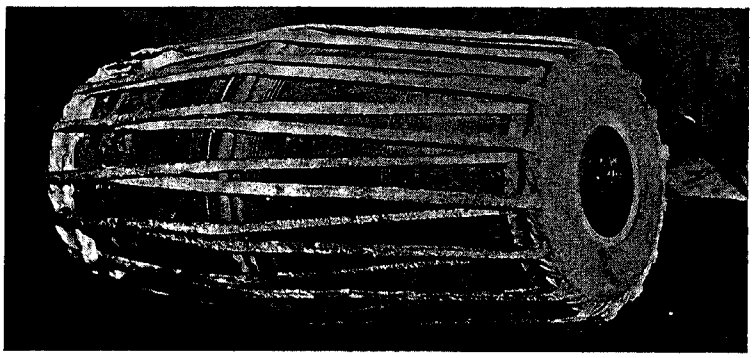


FIG. 2. The Mridanga.

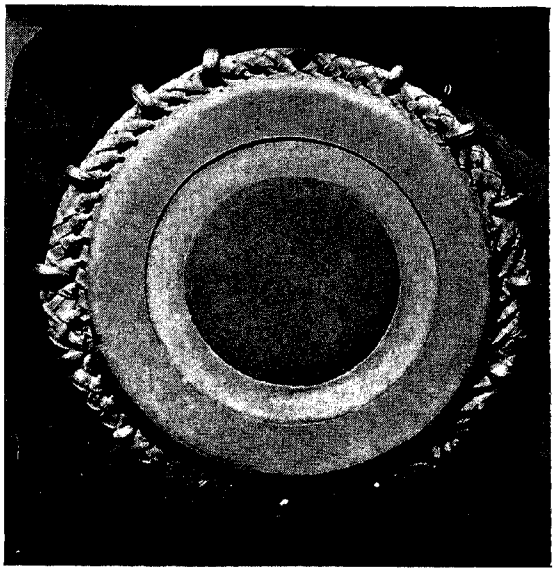


FIG. 3

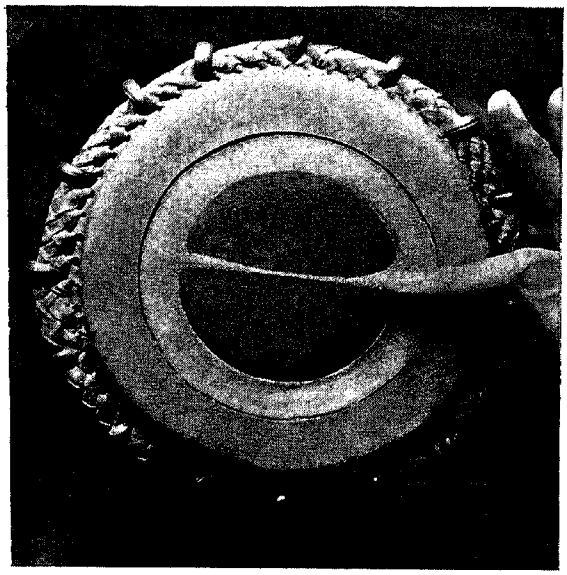


FIG. 4

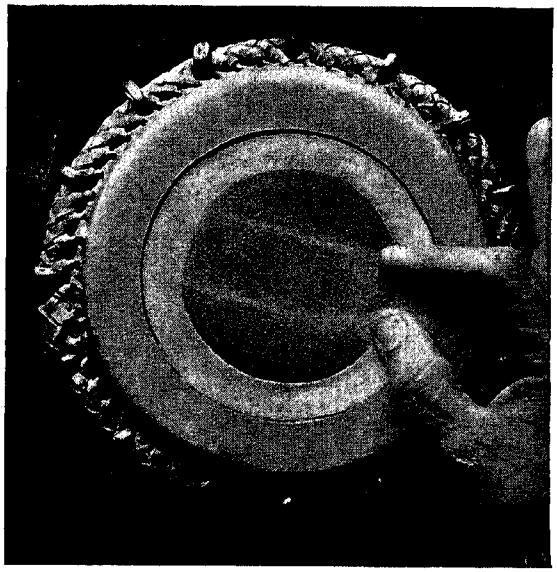


FIG. 5

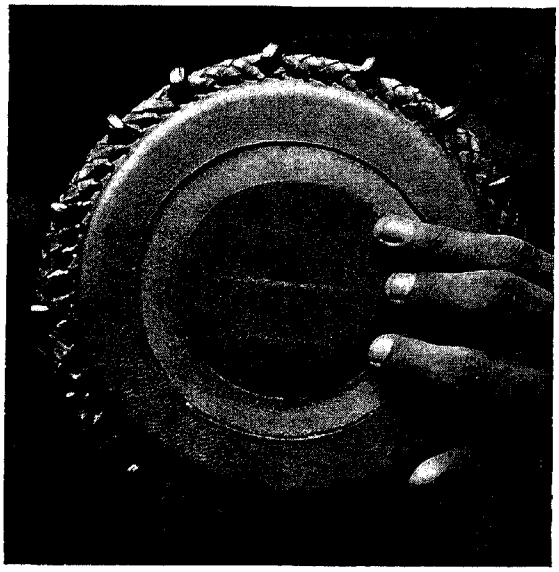
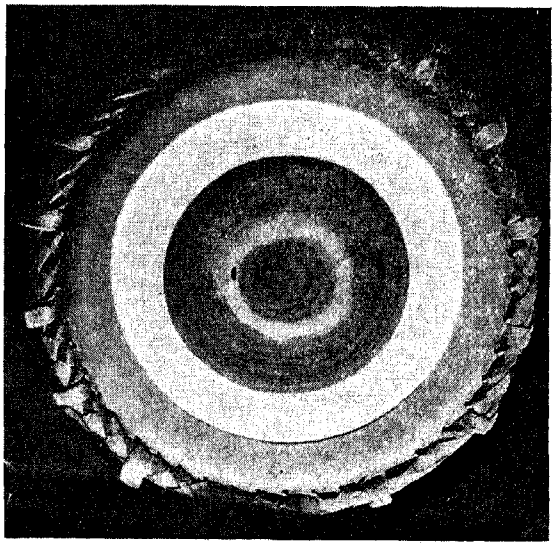


FIG. 6



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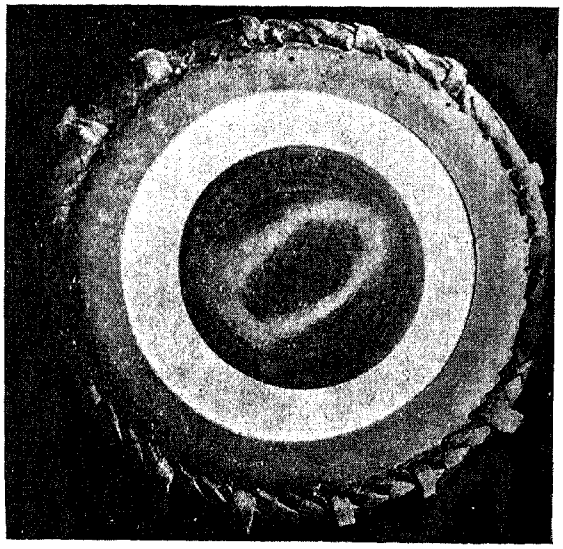

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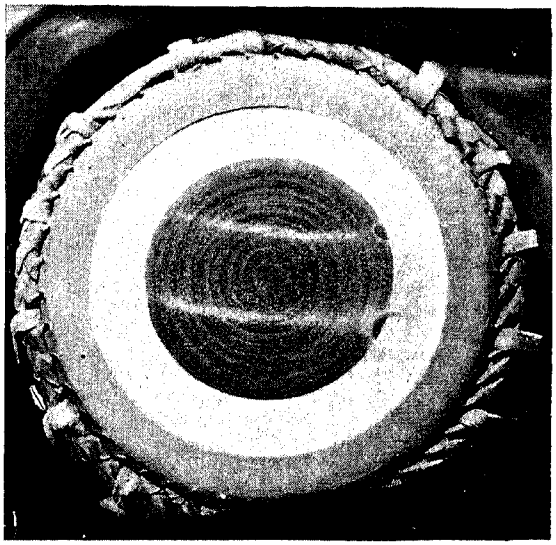
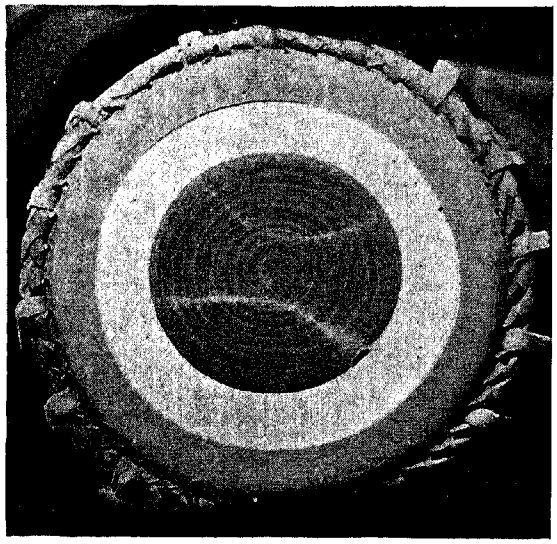


FIG. 9



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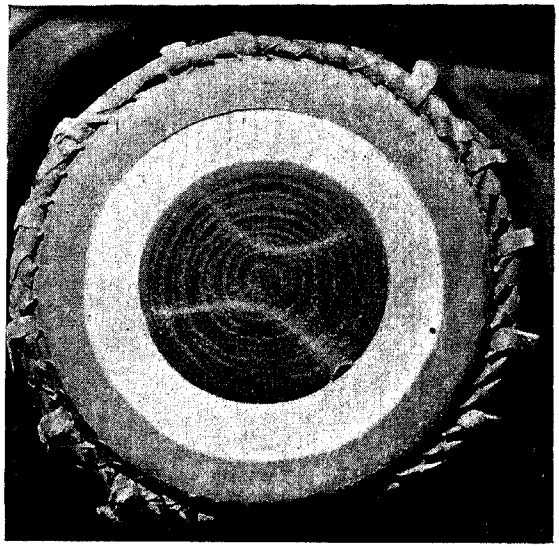
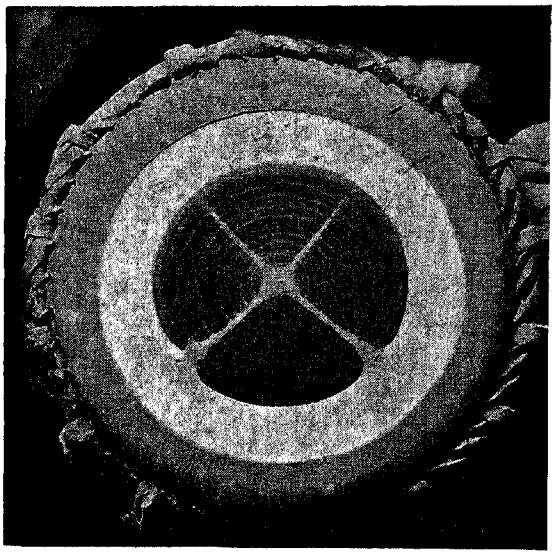


FIG. 11



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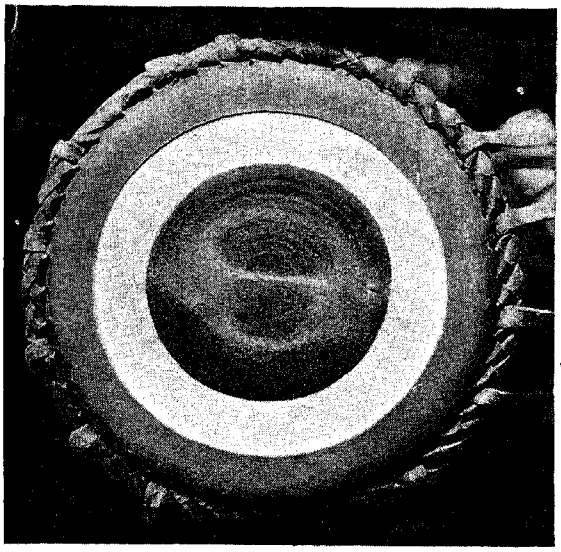
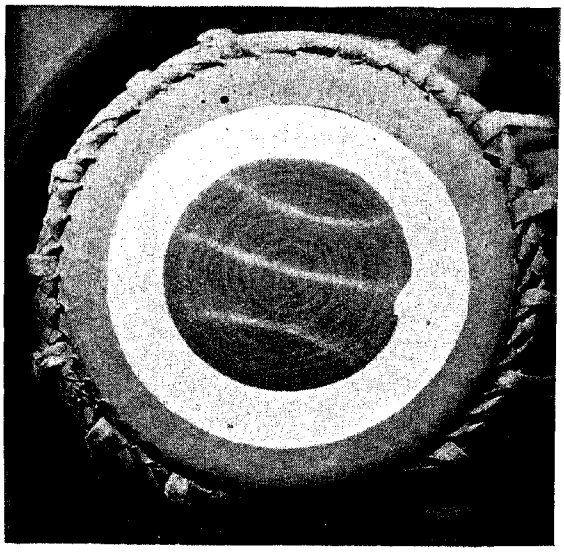


FIG. 13



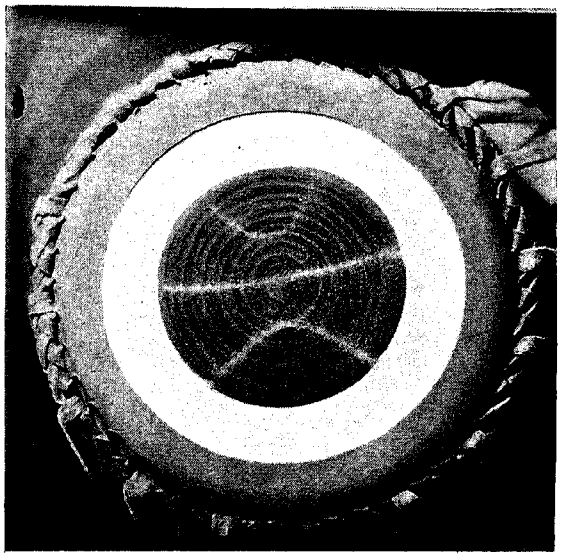


FIG. 15

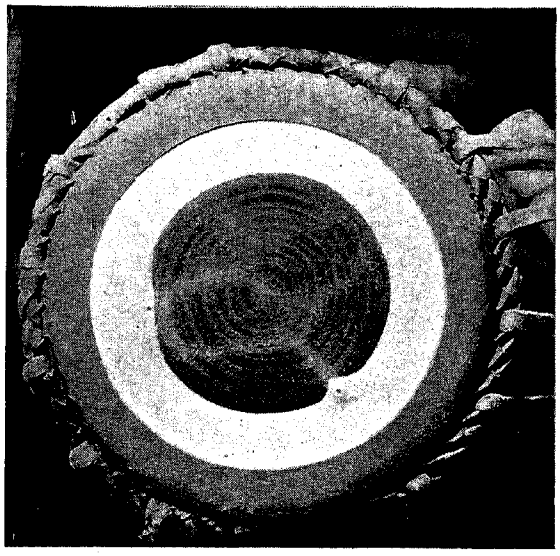


FIG. 17