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A REVIEW ON TUNING OF MUSICAL INSTRUMENTS

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ABSTRACT

Research on musical instruments and their tuning had attracted researchers worldwide. Indian classical music is distinct from western classical music and is unique in its form and presentation. Indian classical music can be divided in two classes (a) Carnatic and (b) Hindustani classical music. Musical instruments used in Hindustani classical music are different in design from the Carnatic musical instruments. Present study involves an exhaustive literature review on tuning of Indian classical musical instruments with a special emphasis on the Hindustani classical music.

KEYWORDS: Tuning, Hindustani Classical Music, Psychoacoustics

INTRODUCTION

A detail discussion on different Indian musical instruments has been put forward by Lalmoni Mishra (1973). He had classified the musical instruments in 4 (four) classes, viz., (1)Tantri Vadya or string instruments, (2) Sushira vadya- wind instruments, (3) Avanadda vadya- percussion instruments and (4) Ghana vadya-solid instruments. He has explained the basics of tuning of instruments in a simplified manner. In the book he has divided tuning methods different instruments in terms of wind and tantric vadya in one class and Avanaddha vadya and Ghana vadya in the other class. Misra (1973) has illustrated the use of monochord of tantra vadya for the tuning. Needless to say here that tuning fork is the simplest instrument to provide the similar tuning apart from the monochord.

Sketches of performances of Indian music in historical places like konark, kahjuraho, markonda and sketches of various instruments are extensively presented at the end of his book by Misra.

PHYSICS OF MUSICAL INSTRUMENTS

An extensive literature is available on the physics associated with music [Helmholtz (1863), Fletcher and Rossing (1991), Rossing (2007), Rossing (2008) and Evans (2011)]. Development of musical notes for western chromatic scale was first developed by Helmholtz (1863). He had reported close relationships between acoustics and psychoacoustics on one hand and musical science and aesthetics on the other. He had proposed that waves generated by musical instruments should be in certain frequency ratios for tuning. For sound waves from different instruments arriving at the brain, there can either be beats or a perfect melody. Helmholtz (1863) defined the dissonance as the relation when two musical tones are sounded at the same time, their united sound is generally disturbed by the beats of the upper partials, so that a greater or less part of the whole mass of sound is broken up into pulses of tone, and the joint effect is rough. On the other hand he had described the consonants by certain determinate ratios between pitch numbers, for which this rule suffers an exception, and either no beats at all are formed, or at least only such as have so little intensity that they produce no unpleasant disturbance of the united sound. These exceptional cases are called Consonances.

The role of inner ear (cochlea) in receiving the acoustic waves and perception by human brain to distinguish different frequencies was also explained by Helmholtz (1863) as well as Howard and Angus (2009). In page 129 of his book Helmholtz had quoted “The end of every fiber of the auditory nerve is connected with small elastic parts…. Set in sympathetic vibration by the waves of sound”.

There are two different classifications of Indian classical music in terms of 22 and 12 tonals [Datta et. al (2006), Sengupta et. Al (2005)]. Bharatmuni proposed 22 sub-tones [Ghosh (1961)] whereas modern tuning considers 12 sub tones. This swarastham or tonal in Hindustani classical music are not in uniform distance in the scale rather they disperse in the scale. It is found that 22 tonal systems is hardly used in Hindustani classical music rather, the 12 tonal systems is more popular [Khan (2004), Krishnaswamy (2003), Kasliwal (2009), Mecca (1993), Indurama (2014)].

TUNING OF MUSICAL INSTRUMENTS

There are different types of tuning systems reported in literature [Wendy (1987), Tennenbaum (1988), and Senior (2011)]. They are briefly discussed below:

Pythagorean Tuning Method

The Pythagorean tuning method is named after the famous Greek mathematician as well as philosopher Pythagoras in the sixed century B.C. This method recognized the simple arithmetical relationship amongst the octaves, fifths, and fourth harmonics [Milne et. al (2007)]. According to this method any interval of the musical scale can be expressed as a ratio rational numbers in the form r = s $2^m / 3^n$ where maximum value of n is 6. In contrast, Burns (1999) had considered higher values of “n”.

In the Pythagorean system, all tuning is based on the interval of the pure fifth in the harmonic series with simple frequency ratios. Thus a pure fifth will have a frequency ratio of exactly 3:2.The weakness of this method is that a series of pure perfect fourth or fifths in cycles will never return to the starting point. This due to the fact that no power of 2 equals a power of 3 for non zero exponents.

Just Intonation (JI) Method/Natural Intonation Method

In just intonation all the notes in the scale are related by rational numbers. It is a harmonic matching in which n-th harmonic of the drone coincides with m-th harmonic of the instrument. This system of tuning is common for orchestra and group performance. The combined spectrum of the drone with its adjacent semitones has a unique quality in this method. But method is scale dependent. For example, tuning for C major is not same as tuning for D major. This method is also known as natural intonation. Carnatic Music follows just intonation method for tuning [Serra et al. (2011)]

Equal Temperament (ET) Method

In this system of tuning adjacent notes differ by a constant frequency ratio of $2^{\frac{1}{12}}$ [Jerald (2007), Hinrichsen (2012)] which equals 100 cents. Here the intervals between adjacent semitones are equal. Tuning through ET by ear is a challenging task usually carried out iteratively in certain interval sequence. Modern method of ET involves electronic devices which automatically recognize the tone, measure its frequency and display the actual pitch deviation from the theoretical value. However, this method is having drawback in correction of inharmonic leading to psychoacoustic out of tune feelings. The inharmonicity is due to the stiffness/inertia of the instrument strings. Rails back (1938) suggested stretching of .an octave over a well tuned piano. Figure 1 presents Rail backs curve compared with a real piano for ET condition.

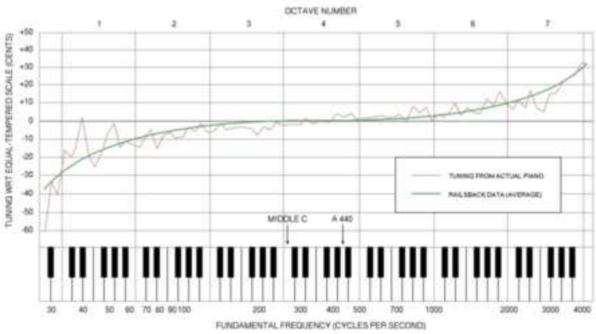

Figure 1: Rail Backs Curve Comparing ET Scale to a Normal Piano

Usually the western musical scales are based on equal temperament (ET) even though certain intervals are worse than their JI counterpart [Krisnaswamy (2003)]. Hindustani classical music tuning is inclined towards ET method with introduction of harmonium Banerjee et al. (http://www.eunomios.org/contrib/banerjee-patranabis-sengupta-ghosh1/banerjee-patranabis-sengupta-ghosh1.pdf) and Banerjee ET. Al (2013).

Harmonic Series Ratio

Mathematically a harmonic series is a series whose terms are in harmonic progression. For example, considering a series, 1+1/2+1/3+1/4+………… Similarly, in music harmonic tones consists of a fundamental tone and consecutive harmonics produced by it. Considering a fundamental frequency of 440 Hz, the frequencies of 220 Hz, 880 Hz, and 110 Hz consists of consequent harmonics. Overtones in the example are 440 Hz and 880 Hz whereas 220 Hz, 110 Hz are under tones. In musical instruments first few ratios of frequencies are of practical importance [Krishnaswamy ((2003)]

Other Methods

There are many other methods of tuning such as simple ratio, mean tone tuning, etc used for tuning of instruments [Serra et. Al (2011), Krishnaswamy ((2003)]. Piece wise linear approximation is also been suggested by Mises and karman (1964) while Hinrichsen(2012) developed an entropy based model for removing the inharmonicity by stretching when there are multiple instruments are played simultaneously. Computational approaches for tuning is attracting researchers for improved tuning [Rao and Rao (2014)], Volk and Honingh ((2012), Rao and Meer (http://autrimncpa.wordpress.com), Dutta et. al (2006), Koduri et. Al (2012)].

Tuning of musical instruments has been the area of research for long time [Dentone (1997), Dahlhaus (1990)]. Physics of tuning is described elaborately by Fletcher and Rossing [Fletcher and Rossing (1991), Rossing (2007), Rossing (2008)]. Importance of musical intervals and scale on tuning is reported by Burns (1999). Western countries follow equal temperament (ET) as convenient method for tuning [Hinrichsen (2012)] whereas just intonation (JI) or natural system is common method for tuning of musical instruments for Indian classical music [Serra et al., 2011]. However, they reported that while the Carnatic music follows just intonation(JI), Hindustani classical music is more or less influenced by equal tempered(ET) system has the strong dependence in tuning in presence of inharmonics [Rails back(1938)].

TUNING OF STRING INSTRUMENTS

An extensive literature is available on stringed musical instruments and their tuning. However, most of the reported literature deals with tuning of single musical instrument [Sengupta et. al, (1983), Dutta et al. (1995), Banerjee and Nag (1985), Vernon (1967), Harkness (1984)].

Studies on self excited oscillations by means of periodic variation of certain parameters in a dynamic system were studied by Lord Rayleigh [Mises and Karman (1964)]. He had demonstrated that the frequency of oscillation of a stretched string attached to a tuning fork appears to be half of that of the tuning fork. Raman (1909) did experiments on a single string instrument one end of which was attached to a board and other end was kept under tension as shown in Figure 2

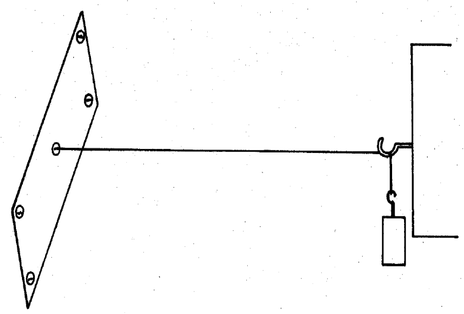

Figure 2: Raman's Experiment

This device represented a simplified model of Ektara or "Gopijantra". He had compared the results with that with that of a sonometer attached with the wire made of same material and dimension. It was reported that the pitch of the note emitted by Ektara to be twice that of the frequency of oscillations of the wire. He had further reported that a faint note at fundamental frequency can also be heard if a resonator is used with the device. Similarly, misra (1973) had explained the effect of string tension, weight of string and relative length of the string on tuning of single string (Figure 3) in a simplified manner.

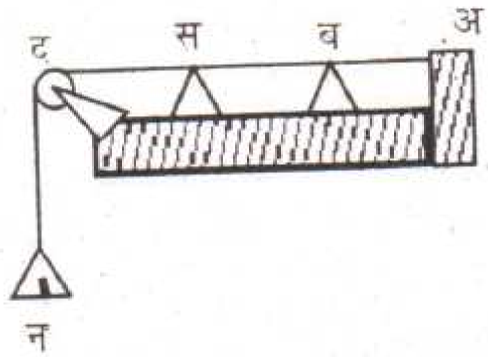

Figure 3: Tuning of Single String

He had illustrated that a string is tightly fixed at location A of a wood log of 36 inch length. This wire passes over two supports at B and C and wire is allowed to pass over a pulley D. The other end of the wire can be loaded with different weights at N. The tension in the string can be increased or decreased with the increase or decrease of weight at N. If we pluck the wire, vibration will be restricted between B and C only. The intensity of vibration can be increased by changing the position of B towards the wood log at A. Thus change of position of location B and change in weight at N are the two possibilities to change the tune. String instruments like sitar, esraj or tanpura can work in the similar principle.

Raman's contributions towards the development of scientific principles are considered to be a pioneering effort towards the construction and achievement of tonal quality of musical instruments [Raman (1910), Raman and Kumar (1920), Raman (1934)]. His monograph on musical instruments and their tones is considered to be one of the references of Indian musical instruments [Raman (1922)]. He had published about 14(Fourteen) papers out of which 13 (Thirteen) were on the theory of violin and 1 (one) on pianoforte.

Raman discussed the physical structure of two major pluck instruments, viz, tanpura and veena [Raman (1921)]. He had mentioned that tanpura contains no frets and is used as a drone in Indian classical music whereas veena is having frets and is used to produce various melodies in performance which depends on the plucking position, length of the string, string materials, etc. However, the major difference of both the instruments is elaborated by him to be in the attachment of the strings over the resonating body by bridges. The strings of the tanpura pass over a curved wooden surface fixed to the body which forms the bridge. He cited “The exact length of the string which actually touches the upper surface of the bridge is adjusted by slipping in a woolen or silken thread of suitable thickness between each string and the bridge below it and adjusting its position by trial. Generally the thread is moved forwards or backwards to such a position that the metal "string" just grazes the surface of the bridge.”

He cited “The form of the bridge of the veena is different than the tanpura, viz, (a) The upper curved surface of the bridge in the "Veena" is of metal, and the special mode of adjustment of contact by means of a thread used in the 'Tanpura" is dispensed with, and the string merely comes off the curved upper surface of the bridge at a tangent. The bridge of the "Veena" is also much higher above the body of the instrument than in the 'Tanpura". Even when the strings are pressed down on the frets when the instrument is being played, the curvature of the upper surface of the bridge ensures the string always leaving the bridge at a tangent to it.”

Sengupta et al. (1983) has discussed on the tonal quality of tanpura while and Dutta et al. (1995) had analyzed the acoustics of tanpura. Sengupta et.al (1983) had described the tunpura to be one of the indispensible musical instruments in performance of classical Hindustani music providing the drones. They had reported that the first string is made of steel and same is tuned to the middle note of the lower octave. The second and the third strings, both made of steel, are tuned to the middle octave. The last (4th string) is made of thick brass wire and is tuned to the first note of the lower octave. Thus the instruments are tuned to 3(three) frequencies, viz., first note to the lower octave, middle note on again to the lower octave, and first note to the middle octave. Tuning frequencies of male and female tunpura (also called tambura) are reported to be 120, 160, and 160, 80 Hz and 180, 240, 240 and 120 Hz, respectively [Fletcher and Rossing (1991), Sengupta et. at. (1985)].They also reported that the tumba (made from dried gourd) attached to the hollow wooden neck acts as a resonator.

Sengupta et al (2005) had studied the dynamic behavior of 15 tanpuras with 4 strings each with fractal dimension, D0 and generalized dimensions, D2 to D10. They had applied fractal-dimensional analysis to relate the apparent non linearity with different part of the signals like attack time, quasi-steady state and decay. Each of the instruments were tuned to Pa (5th note), SA (tonic), SA (tonic) and Sa′ (lower octave tonic). They found that the tuning system obeyed the power law obeying the nonlinearity in the production source system.

TUNING OF PERCUSSION INSTRUMENTS

Extensive experimental as well as numerical studies on Indian drum type of instruments (percussion instruments) are available in literature [Raman and Kumar (1920), Raman (1934), Rossing and Sykes (1982)]. A thorough scientific description on various percussion instruments is reported in the book of Rossing (2000). He had described the vibration of membranes to understand the acoustics produced by drums. The simplest model of the 2-dimensional membrane is represented by a two dimensional string in which the restoring force is due to the tension applied from the edge. Figure 4 presents modes of vibration of a circular membrane.

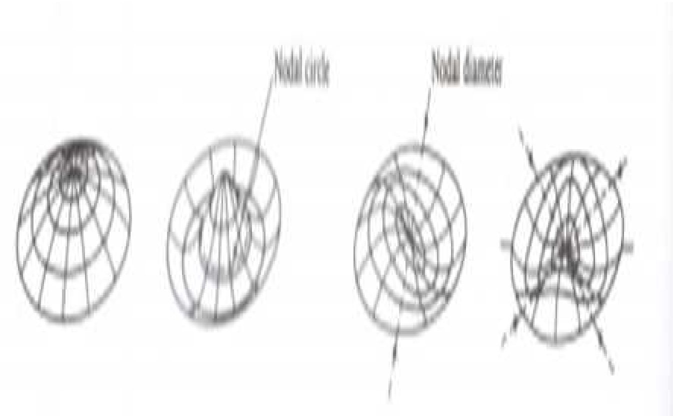

Figure 4: Modes of Vibration of a Circular Membrane
(a) (b) with Circular Symmetry, (c)-(d) Unsymmetric

Rossing (2000) inferred that musical drums with membranes can be tuned by changing the tension. However, major difference between a circular membrane and a string is that the mode frequencies in a string are harmonics of the fundamental whereas membrane frequency is not. Membrane vibration creates nodal lines (circles and diameter) against nodal points created along the length of the string in vibration [Ghosh (1922)]. It may be worth mentioning here that some of the musical drums in India are loaded over a central zone in such a way as to produce harmonic partials. Ghosh (1922) had presented the theory of vibration of such drums for two cases, i.e., (a) when the load varies inversely as the first power and (b) the second power of the distance from the center. He interpreted that in the second case the partials form a harmonic series, whereas in the first case they do not.

Figure 5 presents the first 12 modes of vibration of a circular membrane indicating radial and circular nodes Rossing (2008). The customary mode designation indicates the number of radial mode followed by the number of circular nodes. For example, the 32 mode has three nodal diameters and two nodal circles.

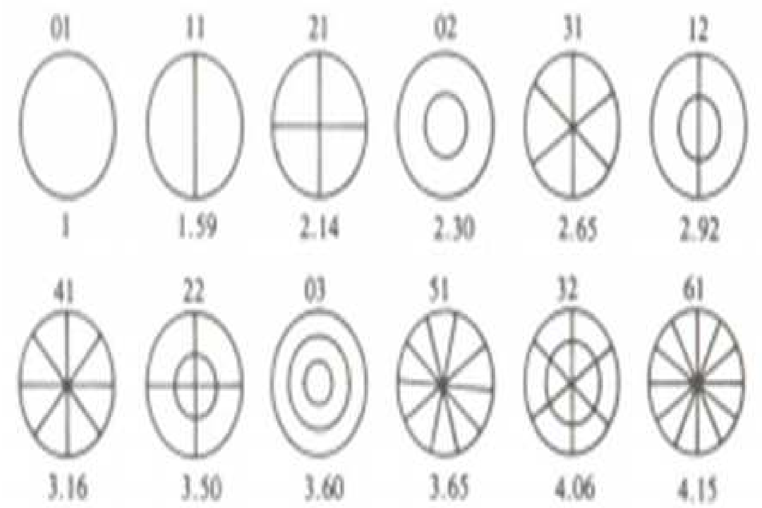

Figure 5: Mode of Vibration of Circular Membrane [Rossing (2008)]

Raman (1922) differentiated the musical properties of tabla and mridanga with ordinary kettle and bass drum. He had reported that both the tabla and mridanga expresses first overtone forms a sequence of natural harmonics with the fundamental frequency. Raman and Kumar (1920) identified first four overtones of the tabla to be harmonics of the fundamental mode. Later Raman (1934) identified these five harmonics as coming from nine modes of vibration. It was also reported by him that several of the harmonics same the same frequency. All the nine modes of nodal pattern are shown in Figure 6.

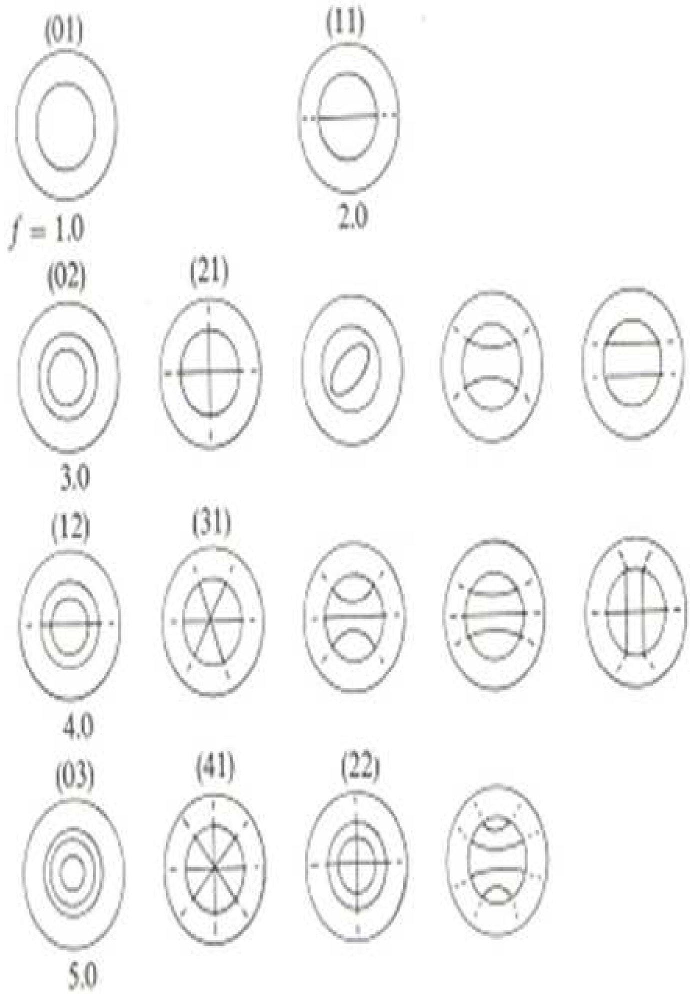

Figure 6: Nodal Patterns of 9 (Nine) Normal Modes and 7 (Seven) of The Combinations Corresponding to the 5(Five) Harmonics of Table or Mridanga Head Harmonic Numbers are Given at the Bottom of the Patterns with Mode Designations at the Top [Rossing and Skyes (1982)]

Patterns of different vibrational modes having frequencies near the third harmonic were obtained by Raman (1934) as shown in Figure 7. These patterns were skillfully obtained by sprinkling fine sand on the membrane of "dayan" before or immediately after the stroke. "Such Chladni or powder patterns indicate that most of the vibrational energy is confined to the loaded portion of the drumhead. This is accentuated by the restraining action of a rather stiff leather flip in loose contact with the peripheral portion of the drumhead. Thus the head is essentially divided into 3 (three) concentric regions. The table player used these concentric regions to obtain three distinctly different sounds, namely, "tun" at the centre," tin" in the unloaded portion and " na" in the outermost portion" [Fletcher and Rossing(1991)].

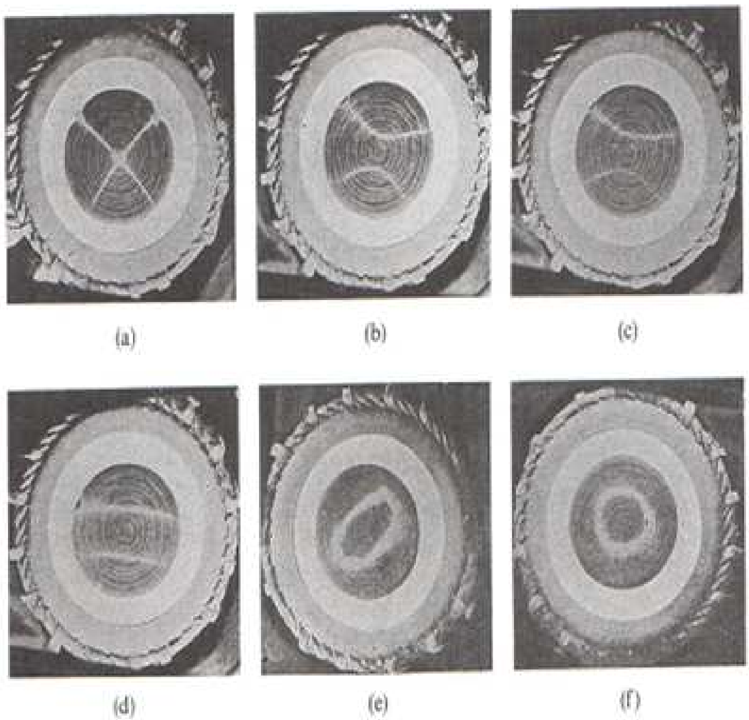

Figure 7: Chladni Patterns of (6) Six Different Modes of Table all are having Frequency near the Third Harmonic. (a) 02 Normal mode, (f) 21 Normal Mode, (b)-(e) Combination of 02 and 21 Normal Modes.

Banerjee and Nag (1984) have discussed on the tuning of percussion instruments like tabla. They had studied on sound of bayan scientifically [Banerjee and Nag (1985)]. Vernon (1967) and Dannenberg and Joseph (1992) had described the recent method of electronic tuning with the use of data acquisition system connected to a computer.

The effect of centre patch on the modes of vibration were studied by Ramakrishna and Sondhi (1954), De (1978) and Sarojini and Rahman (1958). They reveal the area density of the loaded portion of the membrane should be approximately 10 times as great as the unloaded portion. The unloaded portion is having typical area density of 0.02-0.03 gram/cm2 (approx). They also reported that the total mass of the loaded portion is in the range of 9-15 gram.

Rossing and Skyes (1982) studied the effect of central patch on the modes of vibration of a mridanga. Unlike table, the patch in mridanga is prepared before the performance. They prepared a paste made of equal volume of overcooked rice and a black powder composed of manganese and iron oxide. The kneaded materials are pasted layer by layer after cleaning, drying scraping the central portion. A thin layer of overcooked rice was first smeared onto the surface as glue and a small lump of paste was applied. It was smeared out evenly with a swirling motion of the thumb. The excess material was scrapped away with a knife and a smooth rock was used to pack and polish the mixture by rubbing the surface. Variation of frequency of vibration with number of layers applied on the mridanga is presented in Figure 8. It is observed from the figure that 5 harmonic partials in the sound are available for the fully loaded membrane. Several of these partials originate from two or three modes of vibration tuned to have the same frequency with appropriate loading of the membrane. Similar behavior was reported by Raman for tabla [Raman (1934)].

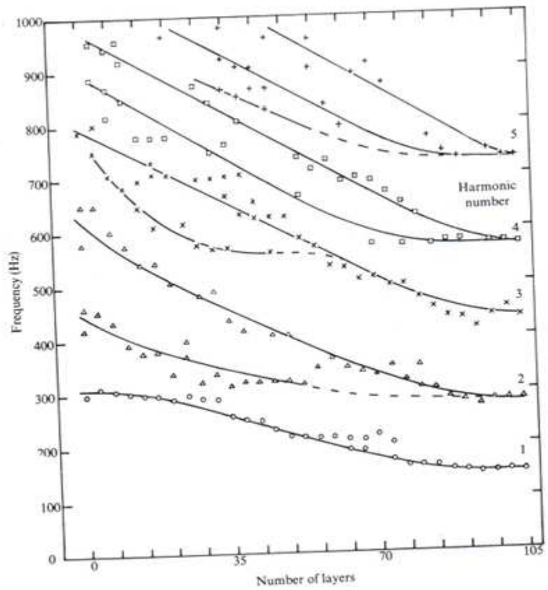

Figure 8: Frequencies of Prominent Partials in Mridanga with Number of Patched Loaded on the Membrane [Rossing and Skyes (1982)].

Damodaran et al. (2015) presented the application of composite materials to the chenda, a traditional Indian drum. They fabricated a sandwich structure composed of carbon fibre/epoxy face sheet and balsa core on which the drum head is attached. The drum shell structure was fabricated by wet lay-up and a vacuum molding technique. They compared the sound characteristics of both the composite as well as wooden drum and found that the frequency response of both the drum were comparable. They concluded that the drum with composite materials to be a promising musical drum with high damping characteristics and same may replace the wooden structure.

Ramakrishna et al.(1957) studied the tonal quality of the “bayan” with an eccentrically loaded membrane. They found the frequency ratios of the lower modes of vibration of this drum-head by replacing the effect of the unloaded annular region with an elastic spring with a suitable variation in its stiffness along the boundary of the loaded region. Ramakrishna and Sondhi (1954) found that the calculated and measured values of the frequency ratios indicate that the overtones of the drum are not harmonic. They also reported that the behavior of the drum head of “bayan” can be approximated to that of the symmetrically loaded “dayan” with application of proper pressure on the annular region at its widest part producing an elicit note approaching to a harmonic.

TUNING REED INSTRUMENTS

Flute acoustics were studied by Dickens (2007). Tuning of several reed types of instruments such as clarinet, alto saxophone and oboe were carried out by Dalmont et al. (1995). They analyzed the effect of the first and the second harmonic resonant frequencies on tuning. Study included the positions of lips and pressure on the reed both theoretically as well as experimentally. Measurements of input data are useful for design of these types of instruments. Inharmonicity of first two resonant frequencies is reported to be either due to the design of instruments or due to embouchure. They further reported that conicity of oboe is solely dependent upon the choice of instrument makers. An exhaustive review on the acoustics of pianos for the period 1920 to 1979 was reported by Suzuki and Nakamura (1990). Terrien ET. Al (2013) demonstrated time and frequency dependency of flute instrument as indicated in Figs. 9 and 10 details of the findings are given in the captions.

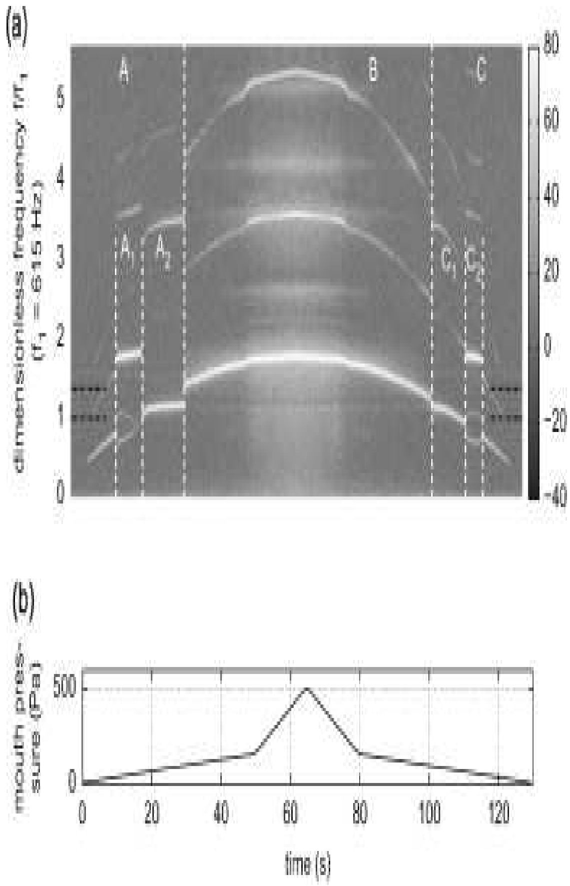

Figure 9: Time–Frequency Representation (a) of the Sound of a Zen-On Bressan Plastic Alto Recorder Played by an Artificial Mouth Making an Increasing and Decreasing Pressure Ramp (b). The Dark Dot-Dashed Lines Indicate the Two First Resonance Frequencies ($f_1 \approx 615$ Hz f1≈615Hz and $f_2 \approx 842$ Hz f2≈842Hz) of The Resonator. G Sharp Fingering (Fourth Octave) [Terrien et. al (2013)]

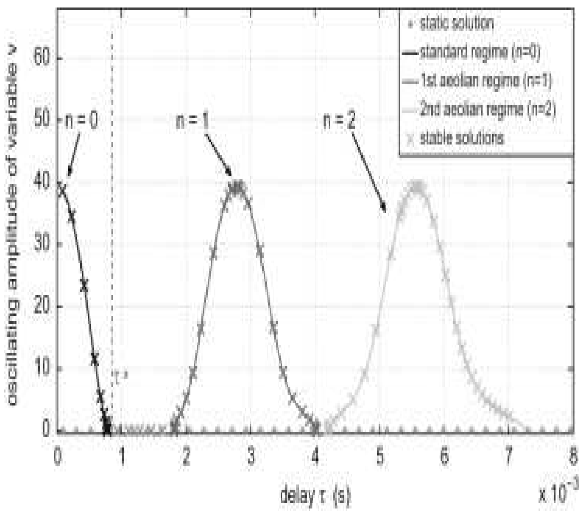

Figure 10: Bifurcation Diagram of System (6). Abscissa: Delay ττ (in Seconds). Ordinate: Amplitude of the Oscillating Variable v (t). Symbols × Indicate the Stable Parts of the Branches, and the Dashed Line Indicates the Separation between the Standard Regime and the Aeolian Ones. Parameter Values: m =1, α=10α=10; a1=70a1=70; ω1=2260ω1=2260; Q1=50Q1=50 [Terrien et. Al (2013)]

PATENTS ON TUNING OF MUSICAL INSTRUMENTS

An attempt was made to search for the patents filed and granted on the tuning of musical instruments. While the number of patents granted for the tuning of western musical instruments were significant, such patents for Indian musical instruments were found to be a few. Claude P Van Ooyen (1965) was granted the US patent number 3183761 for developing a tuner using stroboscopic effect. He had used the magnetic properties of the strings to convert the tuned parameters in terms of frequencies. Weldon ET. Al (1970) patented an electronic tuner for tuning electric guitar. Peter Davidson (1971) patented a similar tuner as a musical reference. However, he used an excitation frequency of 60 Hz whereas same is 50 Hz for the Indian scenario.

Mack worth-Young (1972) claimed a patent to tune musical instruments. It consists of an electric oscillation generator of reference frequency including an array of tuning forks which can be brought, in succession, into register with a driving coil for maintaining the adjacent tuning fork in oscillation. “A pickup coil provides a signal dependent on vibrations of the said tuning fork. The signal is amplified by an amplifier and fed on the one hand to the driving coil and on the other hand to a frequency comparator with a "magic eye." A microphone, for picking up oscillations from a vibratory element of the musical instrument to be tuned, is connected through an amplifier to the frequency comparator”. Table 1 presents a brief list of patents granted on invention of musical tuners.

Table 1: Patents on Musical Tuning and Processes

Title	Applicant	Patent No	Publication Date
Device for tuning stringed musical instruments	Kordick F. (https://www.google.com/patents/US1697508) Regal Musical Instrument company	US1697508	January 1, 1929
Vibrating string apparatus	Klopsteg Paul E. (http://www.google.com.gt/patents/US1908258) Central scientific Company	US 1908258	May 9, 1933
Apparatus for tuning stringed musical instruments	Dickerson Delbert J (https://www.google.com/patents/US2514315)	US2514315	July 4, 1950
Audio frequency meter	Petroff Merlin P. (https://www.google.si/patents/US2779920)	US 2779920	January 29, 1957
Apparatus for electronically tuning an electric guitar	Creamer Weldon, Ferrell Herbert W, Osborn Peter E (http://www.google.co.in/patents/US3501992) Tune Tronics Inc.	US 3501992	March 24, 1970
Apparatus and method for tuning musical instruments	Robert C Mack worth Young (https://www.google.ch/patents/US3631756)	US 3631756	January 4, 1972
Electromechanical transducer for tuning individual strings of a musical instrument	Albertus Cornelis Van De Woerd (https://www.google.com/patents/US3675529) Philips Corporation	US 3675529	July 11, 1972
Combined pick and tuner	Pogoda Gary S. (http://www.google.ch/patents/US4320689)	US 4320689	March 23, 1982
Combined pick and tuner	Pogoda Gary S. (http://www.google.ch/patents/US4365537)	US 4365537	December 28, 1982
Piano tuning mutes	Kovach Bruce F. (http://www.google.co.in/patents/US4452122)	US 4452122	June 5, 1984
Percussion instrument	Mary Dye, Atiba Johnson (http://www.google.ch/patents/US20030061929)	US20030061929 A1	April 3, 2003

Table 1 Continue…………….			
Systems and methods of stretching and tuning drumheads	Krishnamurthy R. (http://www.google.co.in/patents/US8153876)	US8153876 B2	April 10, 2012
Tabla drum head tensioning system and method	David Yovino (https://www.google.ch/patents/US9024162)	US9024162 B2	May 5. 2015
Device and method for tuning an acoustic percussion instrument	Jones Daniel R. (https://www.google.com/patents/US20140202311)	US20140202311 A1	July 24, 2014
Drumhead tuning rim apparatus and method of use	Bryan Thomas Bedson (http://www.google.ch/patents/US8642867)	US8642867 B1	February 4, 2014

Mechanical method of tuning is more popular for the tuning of percussion instruments [Bedson (2014), http://www.google.ch/patents/US8642867]. Dye and Johnson(2003, http://www.google.ch/patents/US20030061929), Krishnamurthy (2012, http://www.google.co.in/patents/US8153876) and Yovino (2015, https://www.google.ch/patents/US9024162) were granted US patents on tuning of percussion instruments. Dye and Johnson (2003) and Krishnamurthy (2012) had described tuning method for percussion instruments closed at both ends like mridangam whereas Yovino (2015) had acquired a patent on tuning of table. Jones (2014) had devised a method to tune a drum head in a single adjustment (https://www.google.com/patents/US20140202311). He used a set of brackets to adjust the tension on the membrane of the drum head.

Krishnamurthy (2012) on the other hand worked on tuning of mridangam to increase and adjust tensions by shortening the length of leather strip (http://www.google.co.in/patents/US8153876). His innovation tuner contains a set of bolts with threaded shank. At least one of the bolts is coupled through threads to a nut. These bolts are equally secured on the periphery of the drum shell. A flexible elongated member is woven alternatively between the drumhead and each of the bolts till the elongated member is taut. The bolt shanks may be rotated relative to the bolt nuts so as to pull the elongated member into a more taut condition, whereby the tension of the drumhead increases.

NUMERICAL SIMULATION FOR TUNING

Recent development in tuning of musical instruments has a trend towards computer simulation [Milne et. al (2007), Wendy (1987), Senior (2011)]. Zwicker and Zwicker (2002) had developed a model to match signals between the musical instruments and receiver, i.e., human brain based on psychoacoustics. Analysis of psychoacoustic response to digital music was discussed by Lopez-Ortega and Frank-Arcega (2015) and they reported significant enhancement of output signal.

PSYCHOACOUSTICS IN TUNING

Tuning of musical system involves physiological and psychological aspects which are nothing but the perception and recognition of the sound of the musical instruments (Helmholtz (1863), Suzuki and Nakamura (1990), Holman (2008), Oxenham (2013). Psychoacoustics has been a subject for therapeutic intervention for different disorders like dyslexia, neurological problems and even in cancer treatments [Poikonen et al. (2016), Mikutta et. Al (2014), Monika (2011), Huss et al (2011), Phipps et al. (2010)]. Hindustani classical music comprises of 7 (seven) notes named as swaras, denoted by Sa, Re, Ga, Ma, Pa, Da and Ni [Serra et al. (2011)]. Moreover, except the tonic (SA) and the fifth (Pa), all the swaras have two variations each counting to total of 12 notes in an octave. These 12 notes are also called swarasthanas and none of them can be fixed as a point on the scale. Thus fixed tuning on each of the notes is not important in case of Indian classical music. Human brain is insensitive to a resolution of 3.5 Hz which indicates that tuning system need not be exact and may have a variation by 3.5 Hz. This is the psychoacoustics of human brain. This gives flexibility in tuning within certain audible limits. Howard and Jamie (2009) have distinguished between the acoustics and psychoacoustics in details.

Fletcher and Rossing (1991) had described psychoacoustic effect on tuning with reference to a spinet piano. It is well established that a piano sounds better if the highest and lowest octaves are stretched to a frequency ratio more than 2:1 depending on the size and other characteristics of the same

CONCLUSIONS

A detail discussion on the tuning of musical instruments is presented in the present paper. It is found from the literature review that the Hindustani Classical music is distinct from western music. Tuning of musical instruments used for the performance of the Hindustani Classical music is complex in nature. Tuning methods are also different for different instruments. Several patents have already been developed for tuning musical instruments. However, there is a demand for easy and quick tuning in this field. Psychoacoustics has to be simultaneously considered while developing the tuning instrument or method rather than analytical approach. In a nutshell, Hindustani classical music cannot be perceived with usual methods of tuning rather it is perceived with a mixture of different type of tuning depending upon the instruments used.

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