CLEARING THE DRUMHEAD BY ACOUSTIC ANALYSIS METHOD

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1 INTRODUCTION

It is commonly acknowledged that, when tuning cylindrical (popular) drums, the acoustic response of the drumhead should be uniform when excited around its perimeter. Worland[1] and Rossing[2] have previously performed detailed scientific analysis of the drumhead tension and response at locations around the perimeter of the drum. Furthermore a number of accounts by drummers and music producers highlight the value of this knowledge, such as those by Ranscombe[3], Seymour[4] and Gatzen[5]. This particular strategy for drum tuning is often referred to as 'clearing' or 'equalising' the drumhead.

Previous research on this subject has predominantly focused on ideal taught membranes, i.e. on a single drumhead. The research presented here looks furthermore at the more common performance scenario where cylindrical drums with two taught membranes are of interest. This research provides analysis of the drumhead response at locations around the perimeter of the drum with particular respect to the value of this knowledge in a music performance and production context. The research shows that a uniform response around the perimeter is indeed possible and quantifiable and, therefore, simple analysis methods can be utilised to assist musicians in clearing the drumhead.

This paper first discusses the key prior literature conducted from both scientific and popular viewpoints. A number of experimentation and analysis is discussed and the results evaluated. Finally, novel display systems are considered in order to assist with quantifying the difference between a cleared and 'non-cleared drumhead', and hence providing a method to assist percussionists and music producers in achieving a desired drum sound.

2 BACKGROUND

The distinctive timbre of a membranophone is produced by complex vibrations causing inharmonic overtones[2]. The physics of acoustic drums can be partially described using circular membrane theory based on Bessel functions. Bessel functions are solutions to Bessel's equation and have been discussed by Rossing and Fletcher in "Principles of Vibration and Sound"[6].

Rossing et al.[7] describe the wave equation for an ideal circular membrane with tension T and area density σ as having the solution:

$$Z(r,\phi) = A_m J_m(kr) e^{\pm jm\phi} e^{j\omega t},$$

where $k = \omega\sqrt{\sigma / T}$. The frequency of the (m,n) mode, of m nodal diameters, and n nodal circles, is given by the nth zero of $J_m(kr)$. The patterns seen in modal analysis of a single membrane are as shown in Figure 1.

The fundamental frequency and second partial are the predominant frequencies produced by a drumhead. These two frequencies, the (01) mode, f_0, and the (11) mode, f_1, are the most powerful modes produced by simple excitation, with the fundamental mode being the predominant frequency produced when the drum is struck at or near the centre of the head. This paper concentrates on the second partial, f_1, or (11) mode of the drum. The (11) mode becomes most prominent when the drumhead is excited around the perimeter, and it is this frequency that is of most concern to expert musicians when they tune the acoustic drum by ear. In a study of single-headed tom drums Worland[1] notes in his conclusion that:

> "the splitting of the (1,1) mode under the twofold perturbation appears to be the largest contributor to the sound of a drum not being in tune with itself."

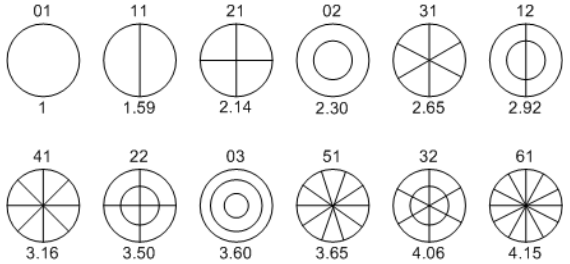


Figure 1: Vibrational modes of a membrane, showing radial and circular nodes and the customary mode designation. The number below each diagram gives the frequency of that mode compared to the fundamental (01) mode (from Rossing[2] p.6).

Worland[1] investigated the (11) mode in drum tuning under non-uniform tension and discusses "frequency splitting", where the (11) mode in a drum with a single head splits into two distinct frequency peaks. He states that in ideal circumstances, "the (11) mode produces a single frequency and occurs with its nodal diameter oriented in any direction." This frequency splitting is also noted in experiments performed on a kettledrum by Rhaouti et al.[8], along with the presence of beat frequencies when these split frequency peaks occur.

Many professional musicians have the ability to tune the drum kit by ear, effectively listening for a desired drumhead response. Gatzen[5] discusses the importance of clearing the drumhead when tuning and explains that

> "Equalised tuning is by far the single most important technique I use"

Many drum tuning guides, for example Ranscombe[3] and Seymour[4], discuss the importance of a uniform pitch around the perimeter. If the frequency response is not uniform these frequencies interfere causing a beat frequency that can be seen in the waveform[9]. Clearing the drumhead, or removing these unwanted frequencies by tuning each point around the perimeter, creates a uniform response which Ranscombe describes as a "nice tone that decays with a smooth even note"[10].

3 EXPERIMENTAL ANALYSIS

3.1 Methodology for analysis

The cylindrical drum used in the following experiments was a 30-cm tom drum from a Gretsch Catalina Club Jazz kit, with an Evans EC2 batter head and Aquarian Classic Clear resonant head. The drum was rested on a standard drum stand with a Shure BETA 57A microphone held securely 10 cm above the drum angled toward the location of the drum stroke. The drum was struck and data captured approximately 5 cm from the edge at 10 locations - one at each lug and also at points equidistant between lugs. A consistent stroke height of approximately 5 cm was used. As the experimental modal analysis used is concerned with the free vibration of the drumhead, precise excitation was not necessarily a significant factor in achieving reliable results.

The acoustic response for each excitation was captured at 44.1 kHz to 16-bit resolution. Using the Matlab Fast Fourier Transform[11], a frequency spectrum is generated from a 5000 sample data window and processed using a Hanning window function. The Matlab FFT function allows use of zero padding[12] to interpolate the raw FFT data, resulting in a smooth spectrum with very close data points. In this instance the FFT was resolved to data points spaced at 0.0842 Hz intervals. Where experiments were performed with both resonant and batter head in place the resonant head was tuned to a desired, uniform response before fine tuning the batter head.

3.2 Clearing the drumhead

It is possible to 'clear' a drumhead by making small adjustments of less than a quarter of a turn to each tension rod (lug) in response to analysis of the frequency spectra for each data reading. Here a uniform frequency response around the perimeter of the drumhead is achieved via analysis of the f_1 mode. This uniform frequency for f_1 can be seen from the results in Table 1 and Table 2 which show the peak frequencies when the response was analysed at 10 locations around the drumhead. These locations are at each lug (1, 2, 3, 4 and 5) and halfway between one lug and the next (1+, 2+, 3+, 4+ and 5+), as shown in Figure 2. The results in Table 1 and Table 2 show that it is indeed possible to tune a drumhead so that each location near the edge of the drumhead has an equal and single identifiable f_1 frequency peak, as can be seen in Figure 3, which relates to the data in Table 1. Table 1 and Table 2 show the uniform frequency achieved at 220 Hz ±0.5 (0.22%) and 175 Hz ±0.8 (0.45%) with both drumheads. These frequencies were specifically chosen to correspond to notes on the musical scale, F3 (174.6 Hz) and A3 (220 Hz).

Figure 4 shows the waveform of a drumhead with a uniform frequency response. Here it is possible to see that a smooth, 'beat free' decay is present. It is thought that, much like the tuning of a timpani, the removal of 'beating' from the waveform is advantageous and necessary in the tuning of a cylindrical drum.

The experimental analysis used shows that when the drumhead has been 'cleared', f_1 is consistent around the drumhead, as shown in Figure 5, which shows results for the 220 Hz tuning used in Table 1; the results have been filtered with a 5th order Butterworth filter applied to $0:5f_1$ to $1:5f_1$ so as to isolate f_1 for analysis. Here it can be seen that f_1 is virtually identical at each point to an accuracy of ±0.5 Hz, and that a smooth decay, Figure 4, is present. This is a novel method for quantifying that a drumhead is in tune by exhibiting a uniform response.

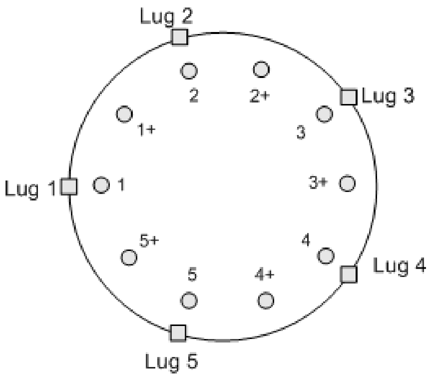


Figure 2: The tuning sequence and stroke locations used on a 5-lug tom drum

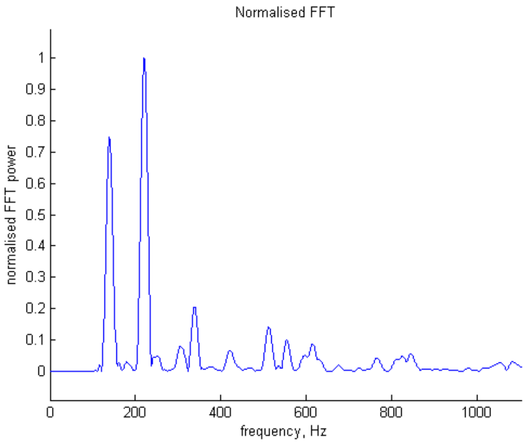


Figure 3: Normalised FFT of the drum acoustic with uniform frequency response struck at the edge.

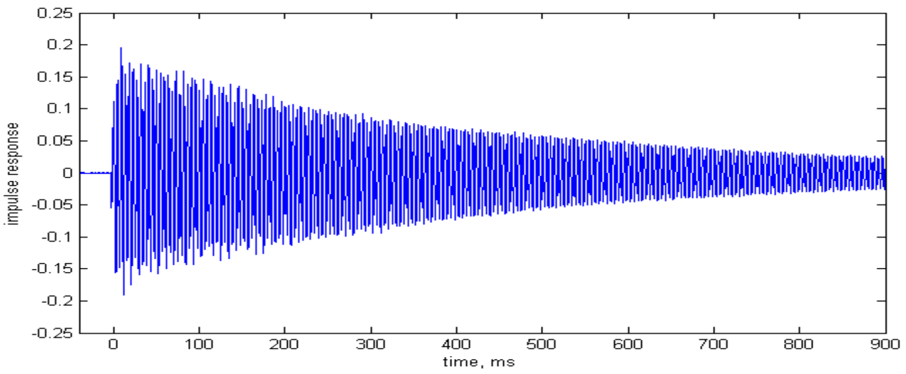


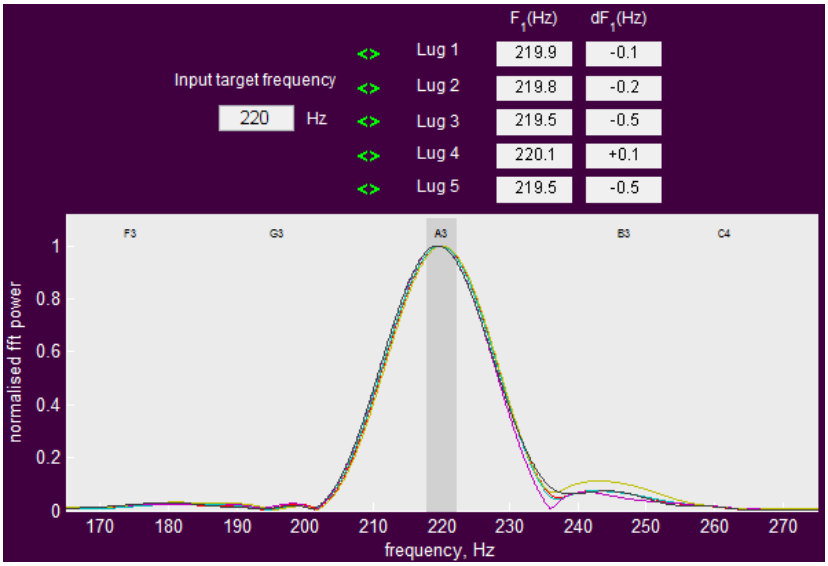
Figure 4: Example waveform produced when uniform frequency for f_1 is achieved for a 30-cm tom drum with a both drumheads.

Tension Rod	1	1+	2	2+	3	3+	4	4+	5	5+
Frequency (Hz)	220.5	220.1	219.7	220.0	220.3	220.5	220.4	219.9	220.0	220.3

Table 1: The average f_1 frequency present around a drumhead on a 30-cm tom drum tuned to 220 Hz with both heads.

Tension Rod	1	1+	2	2+	3	3+	4	4+	5	5+
Frequency (Hz)	175.7	175.5	175.4	175.1	175.0	175.5	175.8	175.1	174.8	175.3

Table 2: The average f_1 frequency present around a drumhead on a 30-cm tom drum tuned to 175 Hz with both heads.


Input target frequency 220 Hz

	F_1(Hz)	dF_1(Hz)
Lug 1	219.9	-0.1
Lug 2	219.8	-0.2
Lug 3	219.5	-0.5
Lug 4	220.1	+0.1
Lug 5	219.5	-0.5

Figure 5: Uniform frequency (220 Hz) for f_1 for a 30-cm tom drum with both drumheads (5th order Butterworth filter applied to band 0:5f_1 to 1:5f_1).

3.3 Identifying anomalies in the tuning setup

Experiments have shown that there are clear fluctuations in the envelope of a ‘detuned’ or 'non-cleared' drum, as also observed by Worland[1]. That is, the drum has been altered in such a way as to no longer meet the tuning criteria of many musicians; a uniform f_1 exhibited around the perimeter of the head and a smooth decay profile.

When one tension rod is slowly altered a quarter of a turn at a time, from 0 turns to 1.5 turns, the peak frequency observed at each lug changes, as shown in Table 3. Figure 6, shows the effect of having a tension rod, in this case tension rod number 3, loosened in quarter-turn increments. The drum was initially tuned to a uniform frequency response and it is clearly visible that frequency splitting occurs as the drum is detuned, and that opposite locations on the drum tend to have similar frequency responses, as shown in Figure 7.

It can also be seen that detuning a single tension rod by just one whole turn has a significant result on the overall spectrum. As one tension rod is altered the frequencies begin to split, and this splitting increases as changes in the tension of the head at a single point and the split between frequencies reaches a maximum of 20.5 Hz at 1.5 turns out of tune. Also it can be seen that although lug 3 is detuned, the maximum frequency change (64 Hz) is at position 3+. This is not surprising as position 3+ is located between lugs and is therefore further away from a fixed tuning point than position 3. Figure 8 shows the waveform produced when a lug is altered by one turn and here it can be clearly seen that the smooth decay of the drum sound is no longer present. Figure 9 shows the f_1 frequency produced by a tom drum struck at each lug. In Figure 9a a uniform f_1 frequency of 220 Hz (A3) can be seen at all locations. Figure 9b shows the same tom tuned to produce a non-uniform f_1 frequency and it can be seen that f_1 at tuning lugs 2 and 5 are within a tolerance of 1% of the desired frequency (220 Hz), whereas lugs 1 and 4 are tuned high and 3 and 6 are tuned low. This non-uniform tuning creates an uneven decay profile for the drum, similar to that as shown, for example, in Figure 10.

A drumhead with a uniform frequency response will produce a smooth decay curve, whereas as the drum becomes less well tuned, the drumhead begins to ‘beat’. The current research shows that a well-tuned drum will minimise beat frequencies. When the drum is tuned, only a single predominant frequency peak is present around the perimeter of the drum. However, as the drum is detuned this main peak frequency splits into 2 peaks, as has also been observed in this research and by Worland[1]. This furthermore correlates with Gatzen’s[5] observation that:

> “You are more able to hear a single pitch the more even your tuning is becoming”

It is possible to define a ‘cleared’ drumhead as one which has a uniform peak frequency response when excited around the perimeter. The waveform of the drum will exhibit a steady decay with no beat frequencies present.

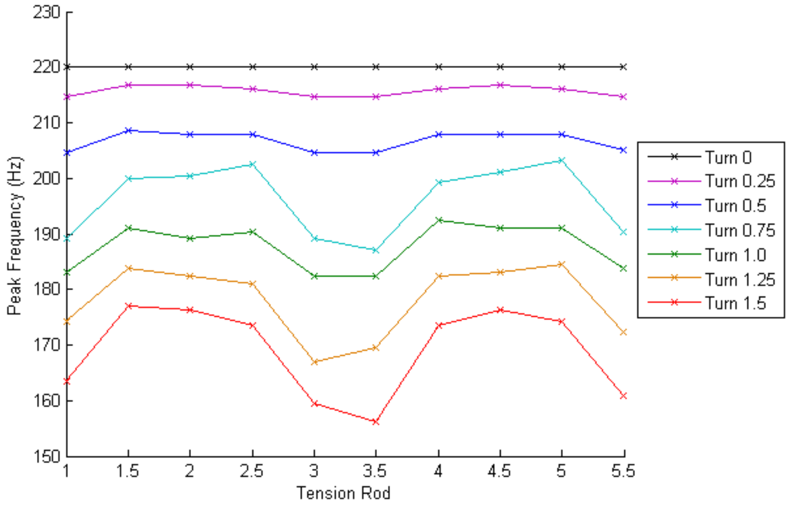


Figure 6: Shows how detuning a single lug affects the peak frequencies around a drumhead.

	Tuning lug									
Tuning	**1**	**1+**	**2**	**2+**	**3**	**3+**	**4**	**4+**	**5**	**5+**
0 Turns	220.1	220.0	220.1	219.9	219.8	220.0	219.9	219.8	220.1	220.0
0.25 Turns	214.7	216.8	216.7	215.3	214.6	214.6	215.8	216.7	215.7	214.9
0.5 Turns	204.6	208.7	207.8	207.8	204.6	204.5	207.2	207.3	207.1	204.8
0.75 Turns	189.4	200.0	200.5	202.3	189.3	187.4	198.9	201.3	203.6	190.8
1 Turn	183.4	191.2	189.1	190.5	182.3	182.4	192.0	191.2	191.3	183.6
1.25 Turns	174.1	184.5	183.1	181.2	166.9	169.8	183.2	184.2	184.7	172.5
1.5 Turns	163.2	176.9	176.5	173.7	159.2	155.9	173.8	176.6	174.1	161.1

Table 3: f_1 frequencies (Hz) around the batter head of a 30-cm tom as tension rod 3 is detuned.

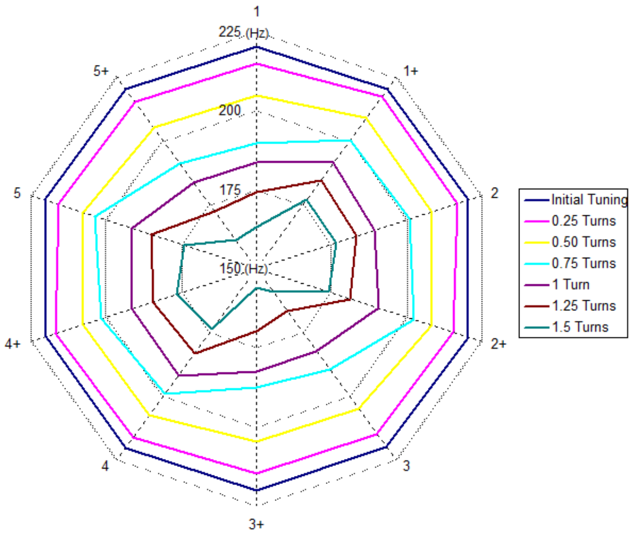


Figure 7: f_1 data from table 3 plotted in a polar frequency chart for each tuning lug

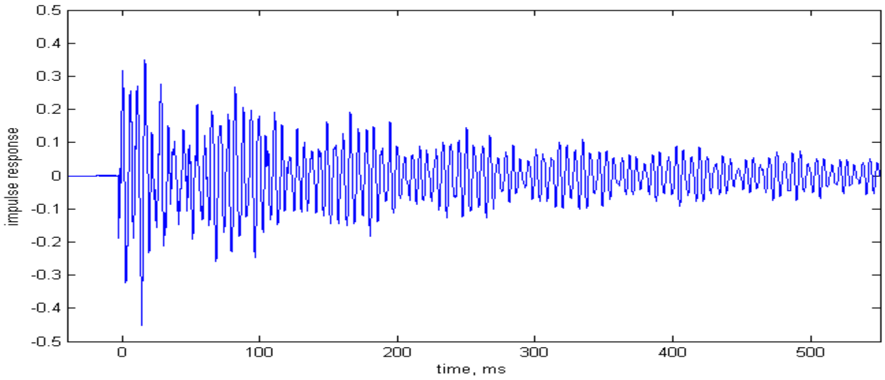
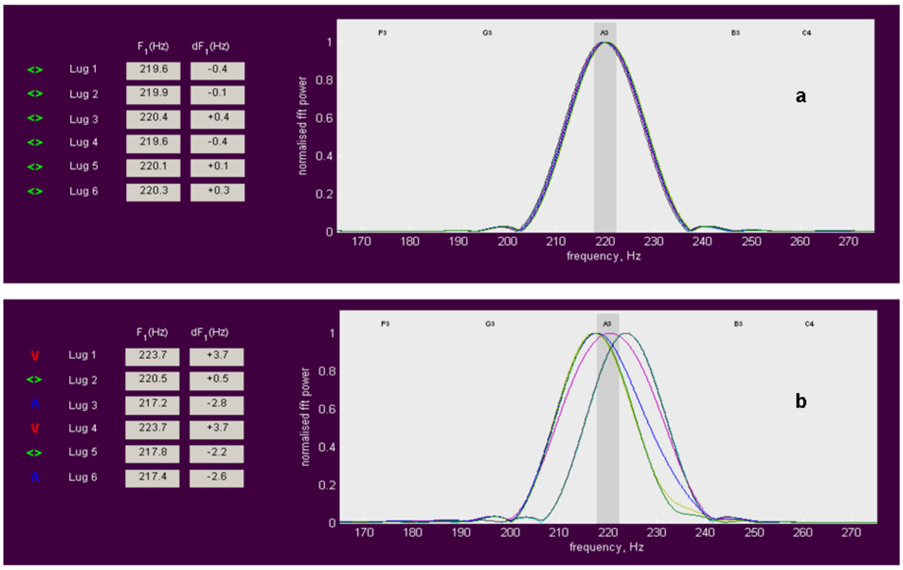


Figure 8: Waveform showing visible beating with one lug altered by one whole turn.



		F_1(Hz)	dF_1(Hz)
<>	Lug 1	219.6	-0.4
<>	Lug 2	219.9	-0.1
<>	Lug 3	220.4	+0.4
<>	Lug 4	219.6	-0.4
<>	Lug 5	220.1	+0.1
<>	Lug 6	220.3	+0.3

		F_1(Hz)	dF_1(Hz)
V	Lug 1	223.7	+3.7
<>	Lug 2	220.5	+0.5
Λ	Lug 3	217.2	-2.8
V	Lug 4	223.7	+3.7
<>	Lug 5	217.8	-2.2
Λ	Lug 6	217.4	-2.6

Figure 9: Analysis of the f_1 frequency for (a) a uniform response and (b) a non-uniform response (5th order Butterworth filter applied to band $0{:}5f_1$ to $1{:}5f_1$).

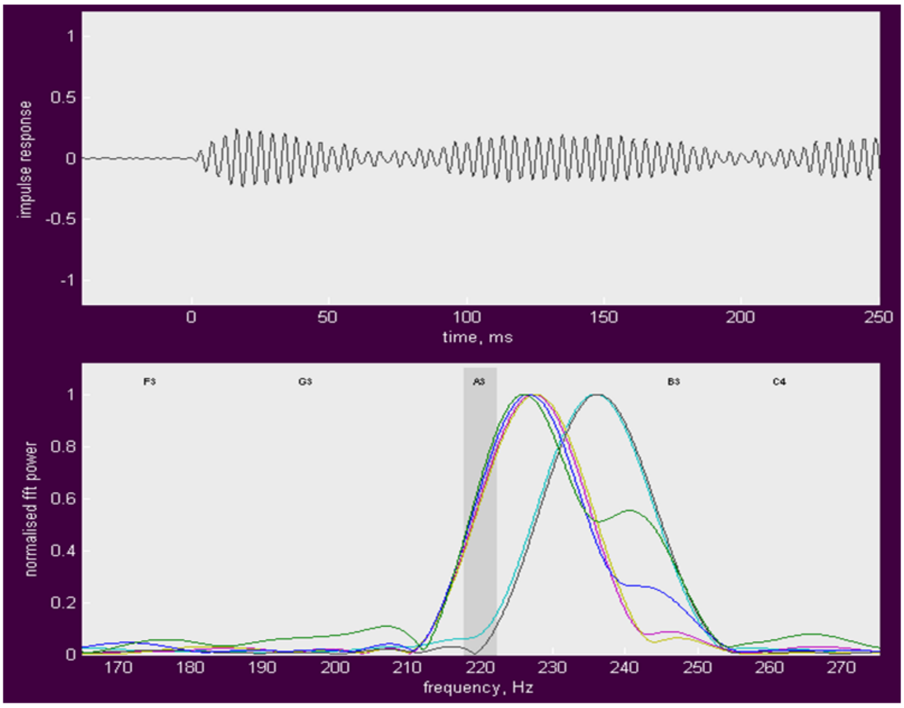


Figure 10: Waveform showing visible beating as the f_1 frequencies diverge (5th order Butterworth filter applied to band 0:5f_1 to 1:5f_1).

4 CONCLUSIONS

The current research shows that uniform frequency responses for the f_0 and f_1 frequencies are achievable for cylindrical drums. This has been shown for a tom drum with both batter and resonant heads in place. It has also been shown that it is indeed possible to tune the f_1 frequency in the drum to a musical note. The current research shows that with respect to achieving an even, consistent decay of the drum waveform, it is achievable to tune the drum to a uniform acoustic response via microphone analysis techniques. The method of scientifically tuning to a uniform frequency response produces a drum sound consistent with the qualitative descriptors used by percussionists.

It has been shown that even small differences in the tuning of the drum can introduce beat frequencies, providing more evidence towards achieving a uniform response when tuning a drumhead in order to produce a drum sound which has a smooth decay.

Frequency mode shapes have been discussed by Rossing[2,7] and Worland[1], but they have not discussed the response of the drumhead at different strike locations as performed in the current research. Past research has focused on the overall response of the drum as opposed to the specific response of the drum when excited in particular locations.

It is these specific responses which are observed when tuning the drum as a musical instrument, multiple strike locations are used to determine whether the drum produces a uniform frequency response around the perimeter. The results show that a drum can be accurately fine-tuned to provide a uniform response around the perimeter, whilst, with only small changes of drum tuning, a frequency split occurs causing the drum to fall out of tune and beat frequencies to appear.

Frequency splitting and the beats in the waveform indicate that a drumhead is no longer in tune with itself. Understanding of these factors in combination with the analysis techniques outlined in this paper can be used in a drum tuning framework. The analysis software used in this paper is capable of providing visual feedback to aid the tuning process. Where frequency splitting occurs, plots of the (11) mode for each hit location are superimposed, providing a visual indication of which tuning rod needs to be altered in order to bring the drumhead into tune with itself.

Given that minimisation of beating in the envelope and frequency splitting in the spectrum are desired attributes, the current research shows that it is possible to achieve these aims by using feedback from the spectra and envelopes. This alters this aspect of drum tuning from an audible process of tuning ‘by ear’, a skill which may take many years to develop, to a visual process where quantified feedback is provided to aid and speed the process of drum tuning.

This research shows a uniform frequency response for the f_0 and f_1 modes is achievable to a high degree of precision (less than 1% difference in values of f_1 when excited and measured around the perimeter of the drumhead). The research concludes that uniform frequency response profiles on a drumhead can be evaluated scientifically via signal analysis.

5 REFERENCES

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