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Grau en
Enginyeria
Química

Treball Final de Grau

Material selection for sound generation system.
Selecció de materials per a sistemes de generació de so.

Dashiell Obradors Prats

June 2014

Universitat
de Barcelona

Dos campus d'excel·lència internacional
B:KC Barcelona Knowledge Campus
HUBc Health Universitat de Barcelona Campus

> *Després del silenci, el que més s'acosta a expressar l'inexpressable és la música.*
>
> Aldous Huxley

Vull agrair a la doctora Mercè Segarra per haver-me guiat en aquest treball que m'he pres amb molt d'entusiasme. Sens dubte, la seva experiència ha sigut l'ajuda que ha fet que aquest treball arribi a bon port.

Gràcies també a en Josep Maria Mayol Puentes per l'ajuda altruista que em va brindar. El seu consell ha significat molt durant aquests mesos de treball.

Thanks to professor Steven Errede from University of Illinois for helping me from so far away.

Vull donar gràcies també als Papas no només per deixar-me convertir la casa en un laboratori durant aquest treball sinó també per tots els ànims i l'ajut constant que m'han aixecat en les meves caigudes. Agrair al Josh i a l'Isaac el fet de poder compartir qualsevol cosa amb ells i aconsellar-me des de diferent punts de vista. Al meu altre germà Jon per ser sempre amb mi per molt que sigui a l'altre punta del món.

Sara, m'has ensenyat a espolsar-me les pors i agafar empenta per arribar allà on jo vulgui. Ja saps lo molt agraït que t'estic i estaré.

Vull dedicar-li aquest treball als meus Iaios. Sempre heu cregut en nosaltres i sempre hem tingut el vostre amor. El Iaio seria feliç de veure'm fer l'última passa en aquest camí. Oi que sí, Iaia?

REPORT

CONTENTS

1. SUMMARY

A **bass drum** is a percussion instrument made by a cylindrical shell and two membranes (drumheads) stretched over it. The batter drumhead is the vibrator element that produces the sound and the shell and the resonant drumhead are the resonant elements that modify it.

Modern music genres seek for certain bass drum's sound: a sound with a **short duration** with **specific timbral characteristics**. In order to achieve this, in recording and live sessions, the resonant drumhead is removed and half of the bass drum is filled with blankets or pillows, to stop the batter drumhead vibration. Also, the sound is processed to achieve the desired sound.

The **objective** of this project is to improve the system's acoustic sound by modifying the resonant drumhead's tension and by applying an acoustic material: polyurethane foam with open cells panels.

The **ideal sound** is obtained using actual techniques and it will be used as **reference**.

All three possible configurations are recorded. With resonant drumhead tuned at: A) higher, B) same and C) lower tune than the batter drumhead. Results are compared with the ideal sound's frequency spectrum. The system's sound is **improved** when the resonant drumhead is **tuned lower** than the batter drumhead. Sound is affected along frequency range from **15 to 500 Hz**.

According to mechanical and acoustic needs it is found that **polyurethane foam with open cells** is the best material to apply to the system. Different models of polyurethane foam panels are discussed.

Next step is recording the system with the optimum configuration and 50% of bass drum's inner area treated with pyramidal polyurethane foam panel. The result is a great intensity decrease (more than expected) along frequency range from **700 to 7000 Hz**. Two more recordings are made with 37'5% and 25% of bass drum's inner area treated.

Results show that the optimum sound is achieved when 50% of bass drum's inner area is treated and the resonant drumhead is tuned (varying tension) lower than the batter.

2. RESUM

El **bombo** és un instrument de percussió que consta d’un cos cilíndric i dues membranes tensades en ell. La membrana colpejada és l’element vibrador que produeix el so i el cos i la membrana ressonadora son l’element ressonant que el modifica.

En gèneres musicals moderns es busca un tipus de so de bombo: un **so curt** amb unes **característiques tímbriques específiques**. Per aconseguir-ho en sessions de gravació o directes, la membrana ressonadora s’elimina i s’omple el bombo amb coixins i mantes per esmorteir la vibració de la membrana colpejada. El so és processat segons els gustos.

L’**objectiu** del projecte és millorar el **so acústic** del sistema modificant la tensió de la membrana ressonadora i aplicant una millora de material acústic: els panells d’escuma de poliuretà de cel·les obertes.

El **so ideal** s’obté utilitzant les tècniques actuals, i serà utilitzat com a **referència**.

Es graven les tres possibles configuracions. Amb la membrana ressonadora en un to: A) més alt, B) igual o C) més baix que la membrana colpejada. Es comparen amb l’espectre de freqüències ideal. El so del sistema és **millorat** quan la membrana ressonadora està afinada a un **to més baix** que la colpejada. El rang de freqüències afectat va dels **15 als 500 Hz**.

Segons les necessitats mecàniques i acústiques s’obté que l’**escuma poliuretà de cel·les obertes** és el millor material per aplicar al sistema. Son comparats diferents models de panells d’escuma de poliuretà.

El següent pas és gravar el sistema amb la configuració òptima i un 50% d’àrea interna del bombo tractada amb panells d’escuma de poliuretà piramidal. S’aconsegueix una gran reducció d’intensitat (més de l’esperada) al rang de freqüències de **700 als 7000 Hz.** Es fan dues gravacions més amb un 37’5% i amb un 25% d’àrea interna del bombo tractada.

L’òptim sonor s’aconsegueix quan s’ha tractat el 50% de l’àrea interna del bombo i la membrana ressonadora està afinada (variant la tensió) a un to més baix que la colpejada.

3. INTRODUCTION

3.1. MOTIVATION

Material engineering is an interdisciplinary field, which deals with the study of matter and applying its properties to various areas of science and engineering. It provides applied solutions to problems related to material properties, improving their quality. This field is one of the reasons of the constant evolution of products that are around us and we use every day.

A lot of fields have benefited from this science, such as medicine, architecture, aeronautics, chemistry, physics, informatics and every field in which a product improvement represents a step forward. This is the reason that this project is focused in material engineering: to provide a solution to a real problem related to materials. The problem to solve is related to the acoustics field. It is needed to find a solution for our sound generation system: a bass drum.

3.2. THE PROBLEM

A bass drum (also called kick drum) is a percussion instrument usually seen on drum kits that is struck with a mace (beater) attached to a pedal to produce the sound. It is the drum with the lowest pitch on the drum set. It is made by a cylindrical shell and two membranes (called drumheads) stretched over it.

As every acoustic instrument it has a vibrator element which produces the sound and a resonant element that modifies that sound giving it certain qualities. In the case of the guitar the vibrator element is the string and the resonant element is the body. For the case of the bass drum the vibrator element is the batter drumhead and the resonant element is the shell of the bass drum and the resonant drumhead (thus its name).

In modern music genres as rock, blues, and sometimes also in jazz, certain bass drum’s sound’s characteristics are wanted. It is wanted a sound with a short duration and with a timbral characteristic typical of its genre.

To achieve this in recording sessions usually the resonant drumhead is removed and half of the bass drum is filled with blankets or pillows to stop the batter drumhead vibration. Then the sound recorded is modified with audio treatment software and electronic devices to achieve the desired sound. In professional recording sessions it is spent a lot of time preparing and looking for the desired sound, and that time costs a lot of money. Also in live situations where the drum kit is amplified using microphones, the bass drum usually is filled with a pillow, the resonant drumhead has a hole where the microphone goes and the sound is processed by electronic devices or audio software too.

This project is focused in the study of this sound generating system to find a solution for this problem by applying material engineering methodology.

4. OBJECTIVES

- Sound improvement of an acoustic system (bass drum) by the variation of drumheads' tension.
- Sound optimization by introducing a material to absorb non-desired frequencies.

5. PREVIOUS CONCEPTS

As the project is focused on the study of a bass drum and materials applied to acoustics, it is important to introduce first some basic concepts about sound physics nomenclature, circular membrane physics and sound absorption properties of materials to facilitate the understanding of the project.

5.1. SOUND PHYSICS NOMENCLATURE

A sound wave is an air pressure disturbance that results from vibration. For any musical instrument, vibration is never simple. It is a sum of diverse modes of vibration (called partials) which frequencies are usually multiple values of a frequency called fundamental (or main frequency). Partials are called harmonics and they form an harmonic serie.

Frequency is defined as the number of cycles completed in one second for a pure sine sound wave. The unit of measurement for frequency is hertz (Hz). So an acoustic instrument produces a sound that is a sum of different frequencies.

The sound **intensity** [1] level is a logarithmic measure of the sound intensity in comparison to a reference level. It can be measured by:

$$L_I = 10 \cdot \log_{10}\left(\frac{I_1}{I_0}\right) \quad \text{(eq. 5.1)}$$

being I_1 and I_0 the intensities measured in (W/m^2) and L_I the sound intensity level measured in (dB).

In this project frequency spectrum graphics will be used to appreciate the characteristics of the sound of the bass drum and its evolution, according to the improvements carried out. These graphics represent a profile of the intensity level along frequency range from 15 to 9000 Hz.

5.2. PHYSICS OF CIRCULAR MEMBRANES

As it was mentioned before a bass drum produces a sound that is a sum of different frequencies. It is caused for its membrane complex vibration. Every **mode of vibration** of the membrane produces one frequency and the result of summing all frequencies is the characteristic sound of a bass drum.

Next figure (figure 5.1) shows the first 12 modes of vibration of an ideal membrane. Above each mode there are two indexes (*m*,*n*) needed to specify the modal vibration harmonics (a circular membrane is a 2 dimensional object).

The letter *m* is the number of nodal diameters and *n* is the numbers of circles. Below each mode the relative frequency to the fundamental (0,1) mode is shown.

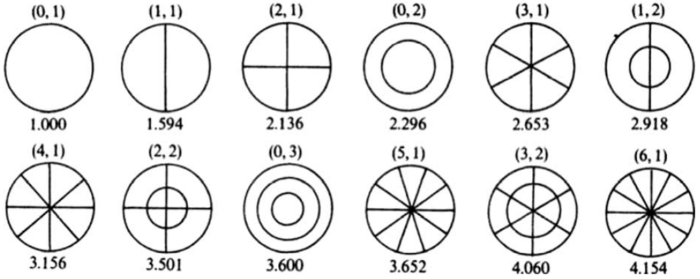


Figure 5.1. First 12 modes of an ideal membrane. [2]

To convert these modes to real frequencies the next equation for ideal membranes is used (eq. 5.2) [3]:

$$f = f_{(m,n)} \cdot \frac{2'405}{\pi} \cdot \frac{\sqrt{T/\sigma}}{D} \quad \text{(eq. 5.2)}$$

Being f the main frequency in (Hz), $f_{(m,n)}$ the relative frequency (dimensionless), T the tension in (N/m), σ area density in (kg/m^2) and *D* membrane diameter in (m).

There are different methods to be able to see modes of vibration in a membrane. For this project the Chladni's pattern experimentation will be applied to the drumheads. It consists in forcing a drumhead (stretched over the bass drum shell) to vibrate in resonance with a sine wave (pure tone) and spreading fine salt (fine particle solid) over it. The salt will be distributed to the lesser energy locations by drumhead's vibration. And this reveals the vibration mode pattern over the drumhead

5.3. SOUND ABSORPTION PROPERTIES

The sound can be absorbed, reflected and transmitted. For this project a material that absorbs the desired incident sound is needed.

Soft porous materials absorb incident, airborne sound waves, converting them into heat. Sound power, even for very loud noise, is small, so the temperature rise is negligible. Porous or highly flexible materials such as polymeric and ceramic foams absorb well. Several mechanisms of absorption are at work here. First, there is the viscous loss as air is pumped into and out of the open, porous structures. Second, there is the intrinsic **damping** in the material. It measures the fractional loss of energy of a wave, per cycle, as it propagates within the material itself.

The proportion of sound absorbed by a surface is called the sound absorption coefficient. The sound absorption coefficients for acoustic materials are usually plotted as a function of frequency (usually for frequency values of 125, 250, 500, 1000, 2000 and 4000 Hz. A value of sound absorption of 1 (100% of absorption) is given to an open window (in each frequency)[4]. A material with a coefficient of absorption of 0’5 means that it absorbs 50% as much sound as an open window of equal area.

6. EXPERIMENTAL MATERIALS AND METHODS

The project is focused to study the possibilities of design and material properties to improve the sound of the bass drum using an internal bass drum microphone and the resonant drumhead. Therefore the tuning of both drumheads must be known. It is needed to study how their tune relation affects the sound and to obtain precise results. For this reason the first part (and a very important one) of the project is to calibrate the Drum Dial.

When the Drum Dial is calibrated, next step will be the recording of the bass drum sound with the traditional recording technique, which is filling the bass drum with blankets without using a resonant drumhead. Thus a sound sample will be achieved (using the same bass drum and the same batter drumhead) and it will be used as the ideal sound to approach with the technique explained before.

After having the ideal sound sample recorded, the project will proceed by making an experiment where the resonant drumhead will be tuned on different tune relations to the batter drumhead. The aim will be to see how the resulting sound is affected by changing the tension of the resonant drumhead. The results will be analyzed and compared to the ideal sound analysis to see which tune relation is the best according the similarities between ideal and new sound samples.

Once the best tune relation is chosen and the frequency analysis is compared to the ideal sound, material selection will be addressed to continue with the improvement of the system’s sound. Edupack will be used as the tool for selecting the material needed according to the properties and characteristics that the material needs to apply to this system.

Then an experiment will be made to see how the chosen material affects the sound by covering different amounts of the bass drum's inner surface with it. The sound samples will be analyzed and compared to see the evolution of the sound sample spectrum with the different amount of treatment. This data will then be compared with the ideal sound sample to see which one is closer to the desired result.

As there are different experimentations in this project to reach different (but non-excluding) objectives, all experimental materials, devices and methods will be explained in this section according to the project phase or part they belong.

6.1. DRUM DIAL CALIBRATION

The Drum Dial® is a device commercialized by Drum Dial Inc. [5] made to know the amount of tension (directly related to tune) applied to the drumhead in every point close to the tension screws. It measures the displacement of the metal gage produced by the tension applied by the drumhead to it in the measure point. In order to view the measure the Drum Dial has a watch with a numeric scale that goes from 0 to 99 (100 is 0) with a large needle that indicates the number according to de drumhead tension. It has also a little needle without a numeric scale that only indicates the number of spins that the large needle does.

The problem with the Drum Dial is that it doesn't give measures of a real tension to translate them to frequencies. So the first step is to find a relation between the Drum Dial measures and the main frequency the drumhead will produce by striking it. To make the calibration of the Drum Dial the Chladni's pattern experiment will be used applied to a membrane using fine salt to see the patterns. The experiment will be made for the batter drumhead and for the resonant drumhead.

6.1.1. Material used for Drum Dial calibration

- Pearl ELX wood bass drum of 22" of diameter (55,8 cm)
- Batter drumhead: Remo Powerstroke 3 of 22" of diameter (55,8 cm)
- Resonant drumhead: Pearl Protone of 22" of diameter (55,8 cm)
- Drum Dial
- Drum key
- 15 Watt Guitar Amplifier with 12" cone (30,48 cm)
- Fender jack to jack instrument cable

- Focusritte Scarlett 18i8 external audio device
- USB to device cable
- Computer
- NHC Tone generator software [6]
- 3 Pieces of wood (with identical height)
- Noise cancelation headphones
- Vacuum cleaner
- Measuring tape
- Lubricating oil
- Fine salt (also can be used fine sand) in a dispenser
- Leveler

Figure 6.1. Upper row from left to right: Drum Dial, drum key, Focusritte Scarlett 18i8. Lower row from left to right: Pearl Protone 22”, Remo Powerstroke 3 22”, bass drum Pearl Export Select 22”.

6.1.2. Experimental device for Drum Dial calibration

The experimental device for the Drum Dial calibration (figure 6.2) consists in a bass drum placed vertically with the drumhead (the sample) stretched over it situated over an amplifier with the help of three pieces of wood to ensure a perfect horizontal placement of the drumhead.

The amplifier, which is located to focus on the center of the drumhead, is connected to a computer via the Focusritte Scarlett 18i8 external audio device. The computer will generate a pure sound (sine wave) with NHC Tone Generator software to make the drumhead vibrate.

To see the different modes of vibration of the drumhead (the membrane) fine salt will be used spread on the drumhead.

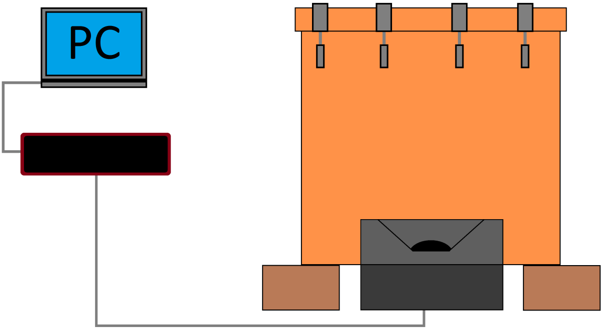


Figure 6.2. Experimental device for Drum Dial calibration.

6.1.3. Experimental method for Drum Dial calibration

1. Mount the batter drumhead to the bass drum and tense the drumhead turning the tension screws with the drum key in half turns in the following order (figure 6.3) until it is hard to continue. Leave it 24 hours with this tension.

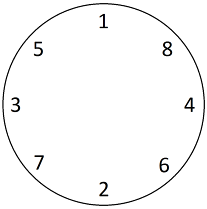


Figure 6.3. Tuning order.

2. After that time loose the screws.
3. Check that the amplifier is connected to the audio device’s output, that it is connected to the computer via USB and that everything is connected to power.
4. Turn on in this order the computer, the audio device and the amplifier.
5. Put the salt in a plate inside an oven at 60ºC to dry it.
6. Open NHC Tone generator.

7. Place the bass drum vertically on the three pieces of wood over the amplifier with the center of the cone aligned with the center of the bass drum.
8. Tense the drumhead turning the tension screws with the fingers until it is too hard. Put some lubricating oil on the screws if it is needed.
9. Take out the plate with the salt carefully and put the salt inside the dispenser.
10. With the help of the drum key tense the screws in the order shown before (figure F.3) in quarter of turns. Measure the tension at the same distance from the edge next to the screw in every measure. The distance must be enough to measure the tension avoiding the muffling ring of the drumhead (6 cm for Powerstroke 3 and 8 cm for Protone) in order to obtain correct measures. Tense until the Drum Dial measures the same value for every screw position.
11. Check that the drumhead is completely horizontal with the leveler and correct it if it is needed.
12. Spread salt on the drumhead surface.
13. Press play on the NHC Tone Generator to generate a sine wave. Turn up the volume of the audio device's output if it is needed. **It is important to wear the noise cancellation headphones to avoid ear fatigue**.
14. Start at 20 Hz sine wave and increase frequency carefully until the drumhead starts to vibrate intensely and the salt clearly reveals the first mode of vibration (a circular node). Write down the frequency given by NHC Tone Generator.
15. Increase frequency until the next mode of vibration is clearly revealed, as marked on the following picture (figure 5.1). It is possible that some of the modes of vibration don't show clearly so collect all the possible results. All the results will be translated to main frequency (mode (0,1)) by dividing given frequency by its related frequency shown below its mode of vibration for a more accurate result.

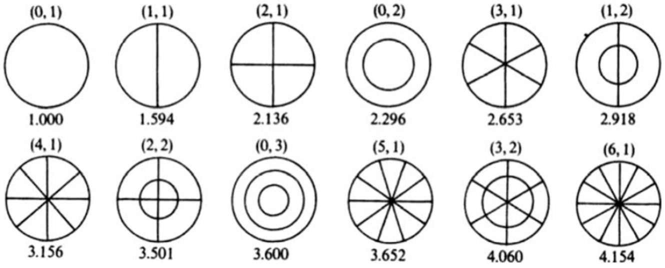


Figure 5.1. First 12 modes of vibration for an ideal membrane.

16. Remove the salt with the air blower.
17. Repeat all steps from point 10 with another desired Drum Dial value (another tension) to collect enough points to have a relation between Drum Dial values and main frequency of the drumhead.
18. Replace the drumhead for the resonant and repeat all points.

6.2. RECORDING OF THE IDEAL BASS DRUM SOUND

To have the ideal bass drum sound the traditional recording technique will be used. This is the technique used in most recording studios and it consists in using only the batter drumhead with the microphone placed close to the opening. The bass drum is filled with blankets in contact with the batter head and covering the inner surface to minimize the drumhead vibration and minimize sound reflection inside the bass drum. Then the sound recording will be treated with compression to have the desired dynamic and equalization to modify the frequency spectrum as wanted.

The resulting sound sample will be the focus of the project as the ideal bass drum sound to approach with design properties and material improvements.

6.2.1. Material used to record the ideal bass drum sound

- Pearl ELX wood bass drum of 22” of diameter (55,8 cm)
- Batter drumhead: Remo Powerstroke 3 of 22” of diameter (55,8 cm)
- DW 5000 bass drum pedal
- Bass drum lifter
- Blankets
- Drum Dial
- Fame MS 112 bass drum microphone
- Microphone stand
- XLR to jack cable
- Drum key
- Focusritte Scarlett 18i8 external audio device
- USB to device cable
- Computer
- Cocko’s Reaper (Digital audio workstation)
- Noise cancelation headphones

- Measuring tape
- Lubricating oil
- Permanent marker

Figure 6.4. Left to right: DW 5000 bass drum pedal, Fame MS 112 bass drum microphone.

6.2.2. Experimental device used to record the ideal bass drum sound

The experimental device (figure 6.4) consists in the bass drum placed in horizontal with the batter drumhead on it and the bass drum pedal attached to it with the hard plastic mace. The bass drum is lifted with the bass drum lifter to ensure that the mace will hit on the center of the drumhead. Inside the bass drum a blanket is placed to muffle the batter drumhead. The microphone is situated in the opening of the bass drum (where the resonant drumhead must be) pointing slightly off center of the batter drumhead (as sound engineers recommend).

The microphone is connected with the XLR to jack cable to the audio device (Focusritte) and it is connected to the computer via USB. Is used Cocko's Reaper [7] (a digital audio workstation) to record the sound.

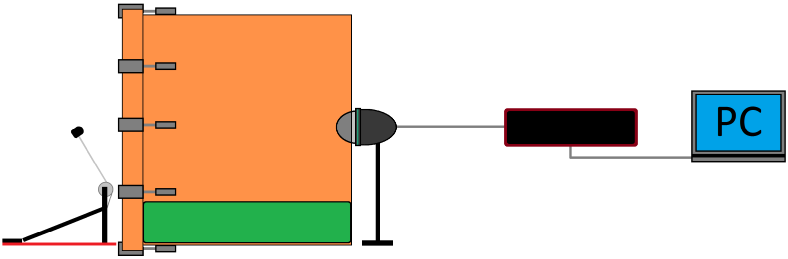


Figure 6.5. Experimental device to record the ideal bass drum sound.

It is important to make the recordings in a treated room to minimize outside sounds.

6.2.3. Experimental method to record the ideal bass drum sound

1. Tune the batter drumhead to desired tuning (according Drum Dial calibration) with the help of the Drum Dial and the drum key using the same methodology explained in experimental method for Drum Dial calibration.
2. Mark the center of the drumhead with the permanent marker.
3. Put the bass drum in horizontal and put blankets inside muffling the drumhead.
4. Put the microphone with the stand in the opening of the bass drum pointing slightly off center of the drumhead.
5. Attach the bass drum pedal to the bass drum using the bass drum lifter to ensure the mace will hit the mark (center of the drumhead).
6. Connect the microphone to the audio device with the cable and the device to the computer via USB and audio device and computer to power.
7. Turn on the computer and then the audio device.
8. Open Cocko’s Reaper and create a new project and track where the microphone will send the signal.
9. Turn up the input volume of the audio device to which the microphone is connected enough to have a good signal without clipping (distortion caused by too much signal).
10. Press record and strike the bass drum using the pedal with the foot. It is enough to make a little jump of the foot on the pedal making sure clipping does not occur. Record some samples.
11. Choose a sample with the maximum volume without clipping and treat it with compression and then equalization until the desired sound is achieved.
12. Export the sound sample in .wav format.

6.3. RECORDINGS WITH DIFFERENT RESONANT DRUMHEAD’S TUNINGS

To see how the resonant drumhead tuning affects the sound of the entire system (bass drum with the batter and the resonant drumheads) it is needed to make at least three sound recordings: one with the resonant drumhead tuned at lower pitch than the batter, one with the resonant tuned at same pitch than the batter and one with the resonant tuned at higher pitch than the batter.

The resulting analysis of sound samples will then be compared to the ideal sound sample analysis to see which result is more alike to the later and therefore used in the next part of the project.

6.3.1. Material used to make recordings with different resonant drumhead’s tunings

- Pearl ELX wood bass drum of 22” of diameter (55,8 cm)
- Batter drumhead: Remo Powerstroke 3 of 22” of diameter (55,8 cm)
- Resonant drumhead: Pearl Protone of 22” of diameter (55,8 cm)
- DW 5000 bass drum pedal
- Bass drum lifter
- Drum Dial
- Fame MS 112 bass drum microphone
- Microphone holder (homemade)
- XLR to jack cable
- Drum key
- Focusritte Scarlett 18i8 external audio device
- USB to device cable
- Computer
- Cocko’s Reaper (Digital audio workstation)
- Noise cancelation headphones
- Lubricating oil

6.3.2. Experimental device used to make recordings with different resonant drumhead’s tunings

The experimental device (figure 6.6) consists in the bass drum placed horizontally with the batter and resonant drumheads on it and the bass drum pedal attached to it with the hard plastic mace. The bass drum is lifted with the bass drum lifter to ensure that the mace will hit on the center of the drumhead.

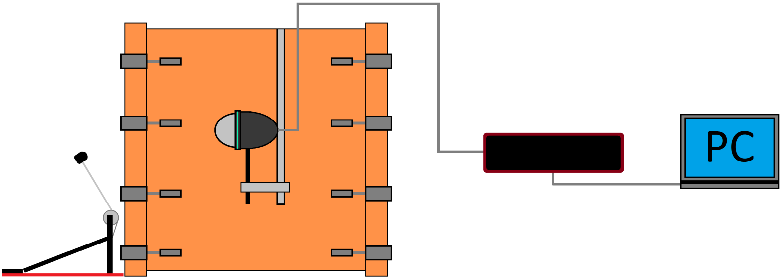


Figure 6.6. Experimental device for recordings with different resonant drumheads' tunings.

The microphone technique is designed to be able to record the bass drum sound using both drumheads and their sound properties. Also it fixes the microphone position to have the same conditions even if moving the bass drum or changing drumheads or making any modifications needed. It is a very useful technique in recording studio sessions or live performances as the microphone is placed in the perfect position according to the drum player or sound engineer.

The microphone is fixed inside the bass drum with the homemade microphone holder. This consists in a tom holder with a double clamp and part of a microphone stand (see figure 6.7) that needed to be cut in order to fit inside the bass drum.

Figure 6.7. Left to right: material used to make the homemade microphone holder, floating microphone system inside the bass drum.

The microphone is placed 21 cm from the batter drumhead (see figure 6.8) and pointing slightly off center of the batter drumhead (as sound engineers recommend).

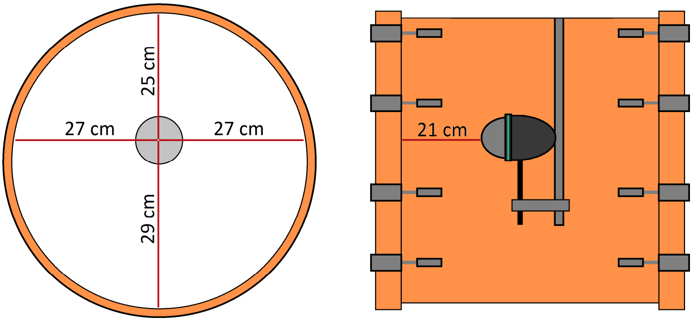


Figure 6.8. Left to right: position of the microphone inside the bass drum in front view and side view.

The microphone is connected with the XLR-to-jack cable through the free hole of the bass drum used as tom holders to the audio device (Focusritte) and it is connected to the computer via USB. Cocko's Reaper (a digital audio workstation) is used to record the sound.

6.3.3. Experimental method to record with different resonant drumhead's tunings

1. Tune the batter drumhead to the same tuning used before (according to Drum Dial calibration) with the help of the Drum Dial and the drum key using the same methodology explained in experimental method for Drum Dial calibration.
2. Put the microphone in the position explained before (figure 6.8).
3. Mount the resonant and tune it at lower pitch than the batter (according to Drum Dial calibration).
4. Attach the bass drum pedal to the bass drum using the bass drum lifter to ensure the mace will hit the mark (center of the drumhead).
5. Connect the microphone to the audio device with the cable and the device to the computer via USB and audio device and computer to power.
6. Turn on the computer and then the audio device.
7. Open Cocko's Reaper and create a new project.
8. Create a new track where the microphone will send the signal.

9. Turn up (or maintain) the input volume of the audio device to which the microphone is connected enough to have a good signal without clipping (distortion caused by too much signal).
10. Press record and strike the bass drum using the pedal with the foot. It is enough to make a little jump of the foot on the pedal making sure clipping doesn't occur. Record some samples.
11. Choose a sample with the max volume without clipping.
12. Export the sound sample in .wav format.
13. Change the tuning of the resonant drumhead (to the same pitch as the batter or at higher pitch than the batter) maintaining the batter drumhead tune. It is needed to have the sound recordings of the three possibilities.
14. Repeat experimentation from step 8 until the three possibilities are recorded.

6.4. SOUND RECORDING ANALYSIS

Audio specialized software is needed to be able to compare between two sound characteristics as sound's envelope and the frequency spectrum. In this case Cocko's Reaper will be used as the digital workstation and Voxengo SPAN [8] will be used to analyze the frequency spectrum. One of the reasons for this is that the full version of Reaper is offered as a free trial version and SPAN has a trial version completely free that allows comparing two different frequency spectrums. The other reason is that these programs are very useful and easy to use.

With these programs it will be possible to see which characteristics are modified (and how much) by changing the tension in the resonant drumhead. Then it will be possible to know which improvements will be needed that will involve other elements such as picking materials to use according to the needs to modify the sound.

6.4.1. Material used for sound recording analysis

- Computer
- Focusritte Scarlett 18i8 external audio device
- USB to device cable
- Cocko's Reaper (Digital audio workstation)
- Voxengo SPAN
- Noise cancelation headphones

6.4.2. Experimental device used for sound recording analysis

The experimental device consists in the computer with the Focusritte connected to it via USB. Headphones may be used to listen to the recordings while analyzing them. To analyze the envelopes of the sound recordings Reaper will be used as it shows the shape of the sound intensity along time. To analyze the frequency spectrum SPAN will be used treating the tracks inside a Reaper file. The MAX option will be used for the spectrum representation. It represents the maximum level reached by each frequency but not the progression along time. It will be used because the bass drum sound that is wanted to achieve is a very short sound.

6.4.3. Experimental method for sound recording analysis

1. Connect audio device to the computer via USB and both to power.
2. Turn on the computer and the audio device.
3. Open Reaper and create a new file to analyze all sound samples.
4. Create a track for every sound sample track and import the .wav files from every recording on its track.
5. To compare all sound envelopes simply edit the recordings moving the start of the sound signal at time 0:00.00 and zoom in to have a clear view. **It is important to have them at the same scale.**
6. Save screen shots of all sound envelopes to then compare them easier.
7. Create a track for the analysis and open Voxengo SPAN in it.
8. Send the signals through the analysis track according those tracks that will be compared.
9. Analyze the recordings using the MAX level option and compare with the ideal sample.
10. Save screen shots of all comparisons and/or single frequency spectrums needed.

6.5. RECORDINGS WITH ACOUSTIC MATERIAL IMPROVEMENT

Once the material needed is found according to results and the mechanical and acoustic properties needed, the next part consists in applying it to the system. The objective of this part is to reduce certain intensity of some desired frequencies in order to have a more similar frequency spectrum to the ideal bass drum sound frequency spectrum. The approach of this objective is to reduce the sound reflections on the bass drum inner surface by applying the material to it.

To be able to see the material improvement effect the bass drum will be recorded with the material applied and the optimum drumheads tuning (or tension) configuration. Then it will be analyzed again and compared with the previous frequency spectrums and sound's envelopes.

6.5.1. Material used to make recordings with acoustic material improvement

- Pearl ELX wood bass drum of 22" of diameter (55,8 cm)
- Batter drumhead: Remo Powerstroke 3 of 22" of diameter (55,8 cm)
- Resonant drumhead: Pearl Protone of 22" of diameter (55,8 cm)
- DW 5000 bass drum pedal
- Bass drum lifter
- Acoustic material (figure 6.9)
- Cutter
- Double sided EVA foam tape
- Silicone
- 8 bar clamps
- 4 wooden sheets
- Drum Dial
- Fame MS 112 bass drum microphone
- Microphone holder (homemade)
- XLR to jack cable
- Drum key
- Lubricating oil
- Focusritte Scarlett 18i8 external audio device
- USB to device cable
- Computer
- Cocko's Reaper (Digital audio workstation)
- Noise cancelation headphones

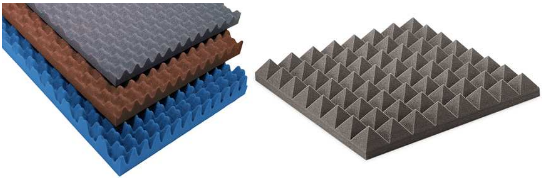


Figure 6.9. Example of acoustic materials (Polyurethane foams).

6.5.2. Experimental device used to make recordings with acoustic material improvement

The experimental device is the same as the one used in recordings using batter and resonant drumheads (section 6.3.2) only adding the material used for acoustic material improvement.

So it consists in the bass drum placed horizontally with the batter and resonant drumheads on it and the bass drum pedal attached to it with the hard plastic mace. The bass drum is lifted with the bass drum lifter to ensure that the mace will hit on the center of the drumhead.

Part of the inner surface of the bass drum is covered by acoustic material (see figure 6.10) to modify the sound according to the needs previously established.

Figure 6.10. Acoustic material improvement for a bass drum.

The microphone is fixed inside the bass drum and placed 21 cm from the batter drumhead (previously seen in figure 6.8) and pointing slightly off center of the batter drumhead (as sound engineers recommend).

The microphone is connected with the XLR-to-jack cable through the free hole of the bass drum used as tom holders to the audio device (Focusritte) and it is connected to the computer via USB. Is used Cocko's Reaper (a digital audio workstation) to record the sound.

6.5.3. Experimental method to make recordings with acoustic material improvement

1. Cut acoustic material in 1/8 of inner area pieces. The pieces must have similar depth as the bass drum (so the other dimension is 1/8 of the inner bass drum's perimeter).

2. Glue double sided EVA foam tape inside the bass drum in three rows along the bass drum depth for acoustic material piece (see figure 6.11). The objective is to cover the 50% of the inner area with acoustic material.

Figure 6.11. EVA foam inside the bass drum.

3. Apply silicone on the EVA foam tapes and glue the pieces of acoustic material to them. Use a wooden sheet and two bar clamps per material piece to apply pressure on them.
4. 24 hours later remove the clamps and the wooden sheets.
5. Tune the batter drumhead to the same tuning previously used (according to Drum Dial calibration) with the help of the Drum Dial and the drum key using the same methodology explained in experimental method for Drum Dial calibration.
6. Put the microphone in the same position as the previous experiment explained before (previously seen at figure 6.8).
7. Mount the resonant drumhead and tune it at optimum pitch (according analysis results).
8. Attach the bass drum pedal to the bass drum using the bass drum lifter to ensure the mace will hit the mark (center of the drumhead).
9. Connect the microphone to the audio device with the cable and the device to the computer via USB and audio device and computer to power.
10. Turn on the computer and then the audio device.
11. Open Cocko's Reaper and create a new project.
12. Create a new track where the microphone will send the signal.

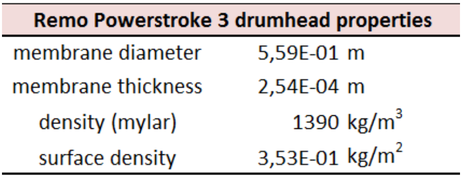
13. Turn up the input volume of the audio device to which the microphone is connected enough to have a good signal without clipping.
14. Press record and strike the bass drum using the pedal with the foot. It is enough to make a little jump of the foot on the pedal making sure clipping doesn’t occur. Record some samples.
15. Choose a sample with the max volume without clipping.
16. Export the sound sample in .wav format.
17. Analyze the sound sample recorded and compare to the ideal.
18. Take or add acoustic material pieces according to the results.
19. Repeat the experimentation with the new amount of inner area treated.

7. RESULTS

7.1. DRUM DIAL CALIBRATION 1

7.1.1. Batter drumhead: Remo Powerstroke 3

The sample (drumhead) has the following properties (figure 7.1):



Remo Powerstroke 3 drumhead properties		
membrane diameter	5,59E-01	m
membrane thickness	2,54E-04	m
density (mylar)	1390	kg/m^3
surface density	3,53E-01	kg/m^2

Figure 7.1. Properties of batter drumhead

The vibration modes that could be observed are marked in red on the next picture (figure 7.2. on next page). The fact that only these vibration modes where able to be observed using the Chladni’s pattern technique may be related in part to the membrane thickness. With a thinner membrane maybe the other modes of vibration could be seen.

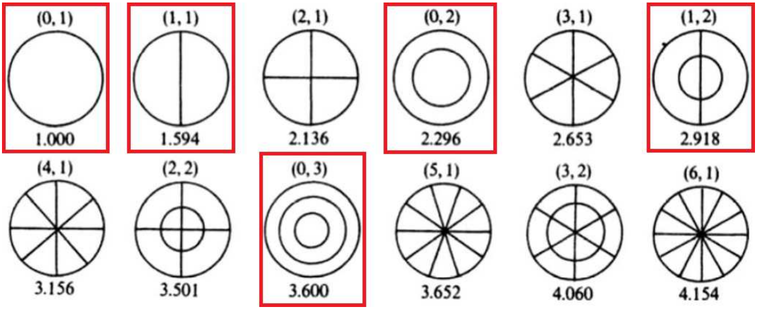


Figure 7.2. Vibration modes seen on batter drumhead

It can also be seen that only two of them contain a nodal diameter. It can be related to the fact that this drumhead has an extra ring layer of Mylar at the edge that makes that kind of vibration difficult.

The results seen with this sample are shown in the next table (figure 7.3):

Vibration mode	[0,1]	[1,1]	[0,2]	[1,2]	[0,3]
Factor	1	1,594	2,296	2,918	3,6
Drum Dial measure	Frequency (Hz)				
3,75	47,7	76,0	109,5	139,2	171,7
3,76	52,0	84,0	121,0	-	185,0
3,77	55,3	92,5	130,0	-	198,0
3,77	59,0	92,5	130,0	166,0	200,0
3,78	60,0	97,0	135,0	177,0	215,0
3,79	62,0	105,0	138,0	185,0	224,0
3,80	64,0	103,0	148,0	186,8	230,4

Figure 7.3. Results for batter drumhead from Chladni's patterns experimentation.

As it is seen in the table the (1,2) mode was hard to see and sometimes impossible (again related to the extra ring). The next picture shows two examples of how different modes of vibration were seen (figure 7.4.) using the experimental device explained before:

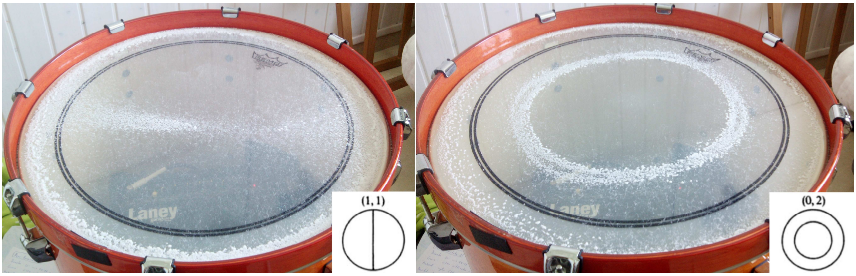


Figure 7.4. Examples of Chladni's patterns seen on the batter drumhead.

Found in the next table (figure 7.5) the translation from the results of all modes of vibration to the main mode frequency. Obtained by dividing by the factors of each mode:

Drum Dial measure	Translation to main mode frequency (Hz)					Mean (Hz)
3,75	47,7	47,7	47,7	47,7	47,7	47,7
3,76	52,0	52,7	52,7	-	51,4	52,2
3,77	55,3	58,0	56,6	-	55,0	56,2
3,77	59,0	58,0	56,6	56,9	55,6	57,2
3,78	60,0	60,9	58,8	60,7	59,7	60,0
3,79	62,0	65,9	60,1	63,4	62,2	62,7
3,80	64,0	64,6	64,5	64,0	64,0	64,2

Figure 7.5. Results for batter drumhead translated to main mode and its mean.

Results previously obtained are represented in the next graphic (figure 7.6) as the relation between Drum Dial measures and the main pitch of the batter drumhead.

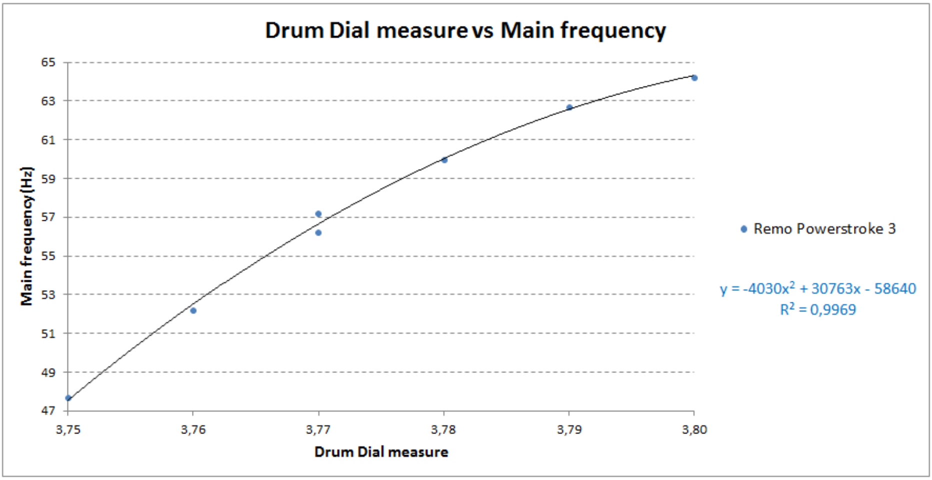


Figure 7.6. Relation of Drum Dial measures vs main frequency for batter drumhead.

The resulting expression for a two-grade interpolation of the represented values is::

$$f = -4030 \cdot x^2 + 30763 \cdot x - 58640 \quad \text{(eq.7.1)}$$

Where f is the main frequency the batter drumhead will produce by strike. This is the relation of frequency with Drum Dial measures for this drumhead (Remo Powerstroke 3) measured at 8 cm from the edge. Thereby it will be able to tune this drumhead at desired tone.

The equation for ideal circular membranes is:

$$f = f_{(m,n)} \cdot \frac{2{,}405}{\pi} \cdot \frac{\sqrt{T/\sigma}}{D} \quad \text{(eq. 5.2)}$$

Being f the main frequency in (Hz), $f_{(m,n)}$ the relative frequency (dimensionless), T the tension in (N/m), σ area density in (kg/m^2) and *D* membrane diameter in (m). Using this expression (with a $f_{(m,n)}$ value of 1) Drum Dial measures in these conditions can be also converted to the tension as show in the next table (figure 7.7):

Drum Dial measure	Mean (Hz)	Tension (N/m)
3,75	47,7	428,5
3,76	52,2	513,2
3,77	56,2	595,9
3,77	57,2	616,6
3,78	60,0	678,3
3,79	62,7	741,0
3,80	64,2	776,8

Figure 7.7. Conversion from frequency to tension of batter drumhead's results.

7.1.2. Resonant drumhead: Pearl Protone

The sample (drumhead) has the following properties (figure 7.8):

Pearl Protone drumhead properties		
membrane diameter	5,59E-01	m
membrane thickness	1,90E-04	m
density (mylar)	1390	kg/m^3
surface density	2,64E-01	kg/m^2

Figure 7.8. Properties of resonant drumhead

The only vibration mode that was able to be seen was the first, the (0,1) mode. And it can also be translated to tension using the equation for ideal membranes (eq. 5.2). So the results are:

Drum Dial measure	(0,1) mode Frequency (Hz)	Tension (N/m)
3,7	36,5	187,7
3,72	39,4	218,8
3,74	43,0	260,6
3,75	44,5	279,0
3,77	47,5	317,9
3,79	50,5	359,4

Figure 7.9. Results for resonant drumhead of Chladni's patterns experimentation.

As can be seen, between results for the batter drumhead and the resonant drumhead (figures 7.7 and 7.9) membrane thickness (in eq. 5.2 related directly to surface density σ) has a big effect to the tone. To generate same vibration frequency (47'7 Hz for the batter drumhead and 47’5 Hz for the resonant drumhead) more tension is needed in the batter drumhead (428’5 N/m) than in the resonant drumhead (317’9 N/m).

Results previously obtained are represented in the next graphic (figure 7.10) as the relation between Drum Dial measures and the main pitch of the resonant drumhead:

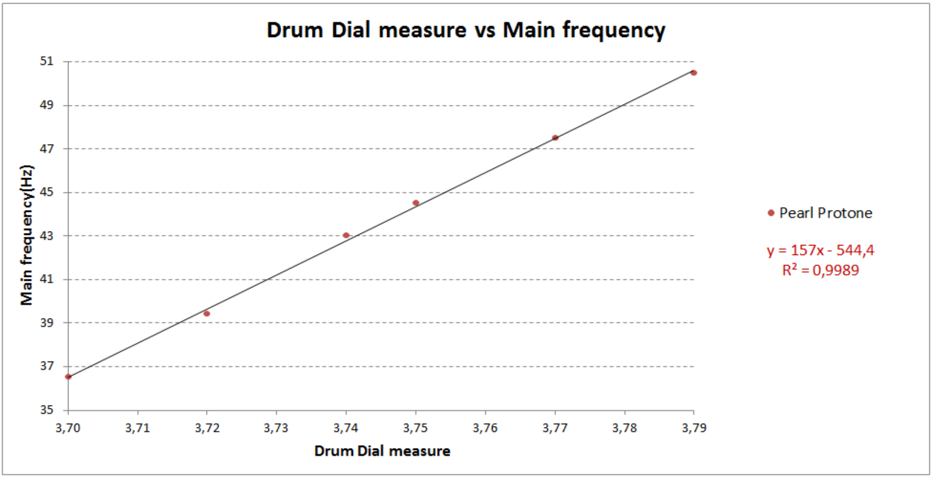


Figure 7.10. Relation of Drum Dial measures vs main frequency for Pearl Protone.

As can be seen, the result of a one-grade interpolation of the results is:

$$f = 157 \cdot x - 544'4 \quad \text{(eq.7.2)}$$

Where f is the main frequency at which the resonant drumhead will vibrate in resonance. This is the relation of frequency with Drum Dial measures for this drumhead (Pearl Protone) measured at 6 cm from the edge.

7.2. RECORDINGS WITH DIFFERENT RESONANT DRUMHEAD'S TUNINGS

The next picture shows the frequency spectrum of the ideal bass drum's sound:

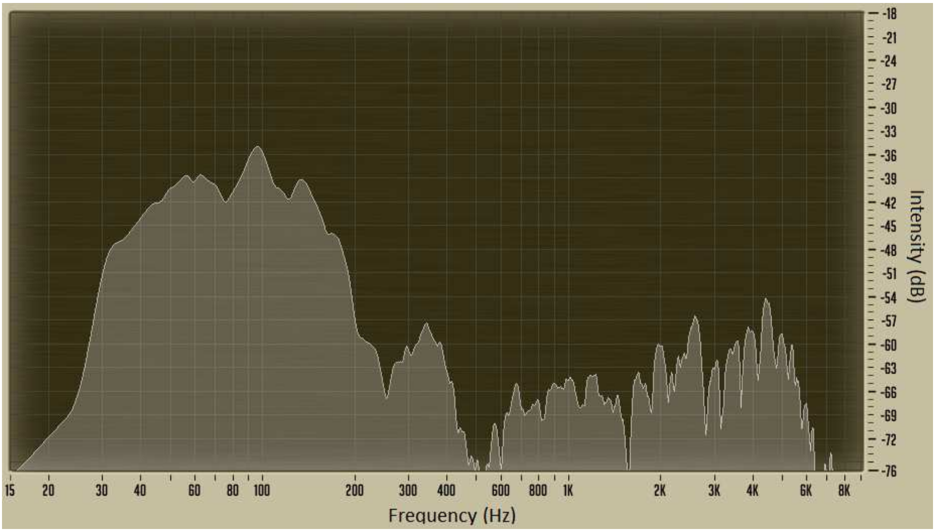


Figure 7.11. Frequency spectrum of the ideal bass drum's sound.

And its sound's envelope:

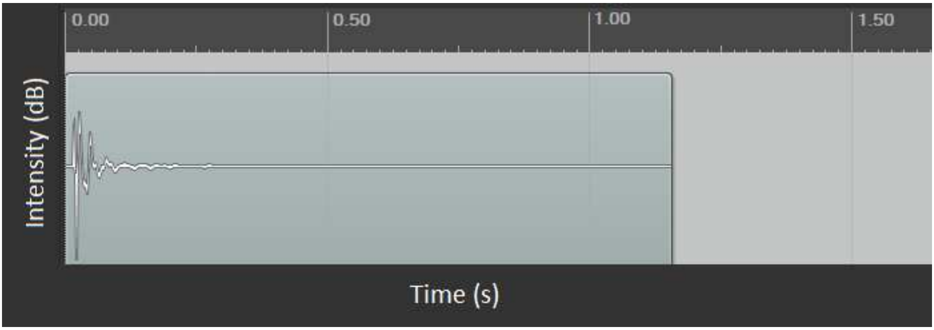


Figure 7.12. Sound's envelope of the ideal bass drum's sound

The objective is to find the optimum resonant drumhead's tension (related to tuning) to generate a short sound (as seen in figure 7.12) with a frequency distribution (as shown in figure 7.11).

For the same batter drumhead tuning (Drum Dial value 3'755 so 50 Hz and a tension of 472'4 N/m) the results for different resonant drumhead tensions are:

A. Resonant drumhead tuned at higher pitch than the batter drumhead (DD = 3’84, f = 58’5 Hz, T = 451’2 N/m)

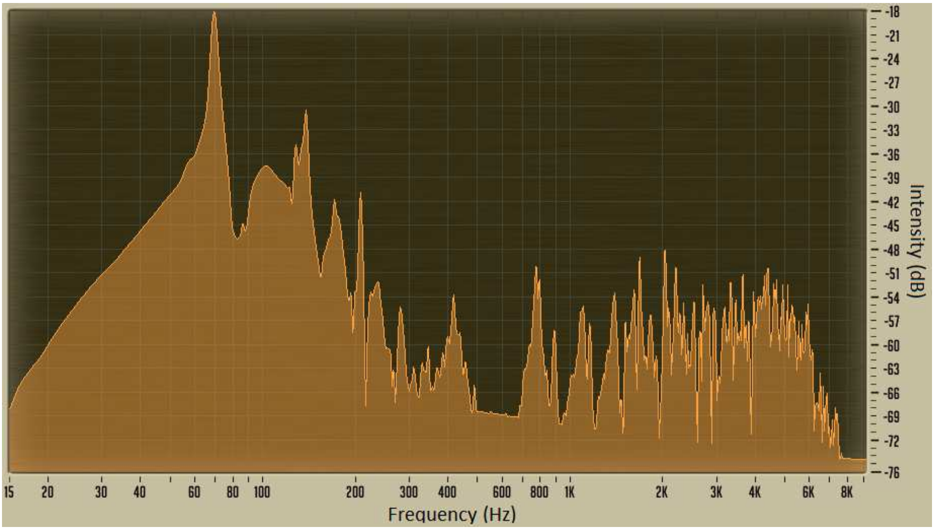


Figure 7.13. Frequency spectrum of the system with the resonant drumhead tuned at higher pitch than the batter drumhead.

And its sound’s envelope:

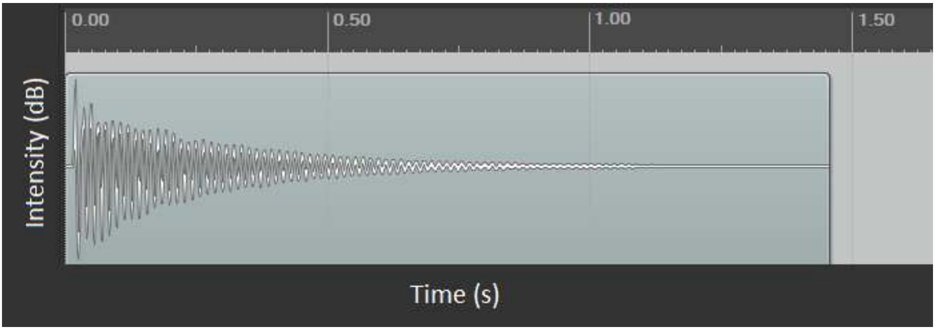


Figure 7.14. Sound’s envelope of the system with the resonant drumhead tuned at higher pitch than the batter drumhead.

B. Resonant drumhead tuned at same pitch than the batter drumhead (DD = 3’786, f = 50 Hz, T = 374’3 N/m)

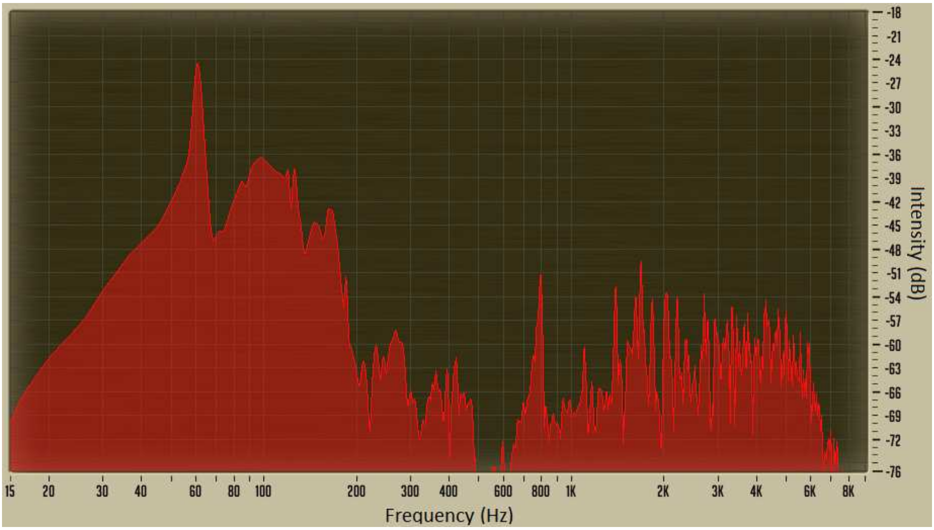


Figure 7.15. Frequency spectrum of the system with the resonant drumhead tuned at the same pitch than the batter drumhead.

And its sound’s envelope:

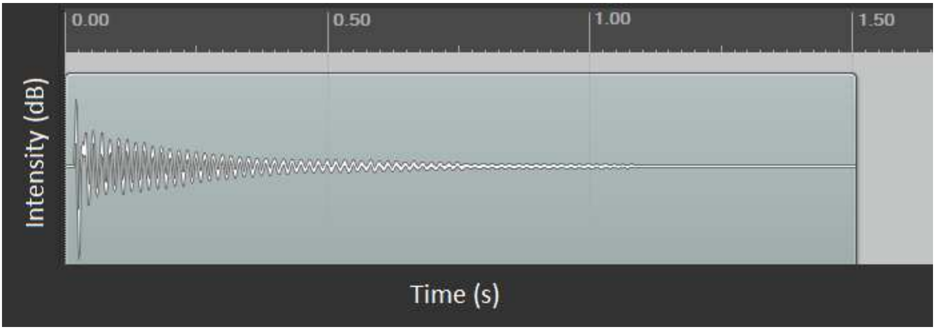


Figure 7.16. Sound’s envelope of the system with the resonant drumhead tuned at the same pitch than the batter drumhead

C. Resonant drumhead tuned at lower pitch than the batter drumhead (DD = 3’70, f = 36’5 Hz, T = 181’8 N/m)

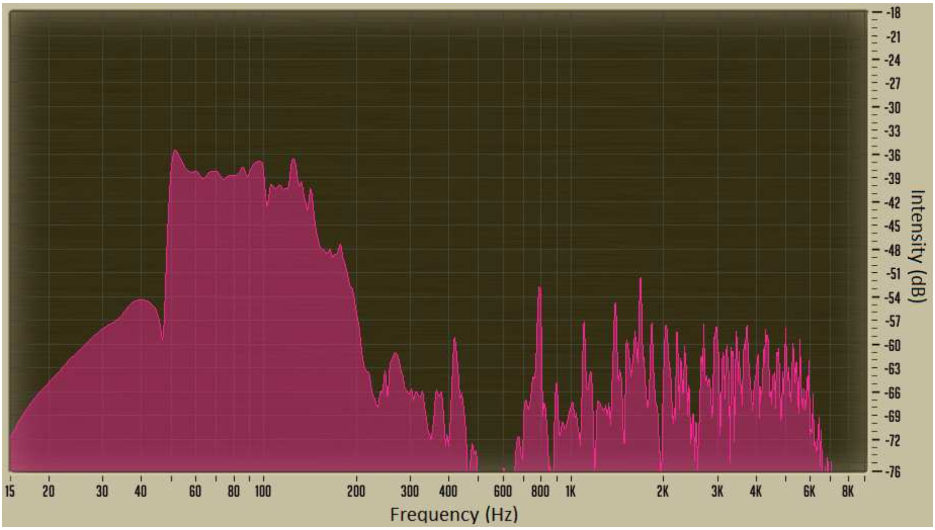


Figure 7.17. Frequency spectrum of the system with the resonant drumhead tuned at lower pitch than the batter drumhead.

And its sound’s envelope:

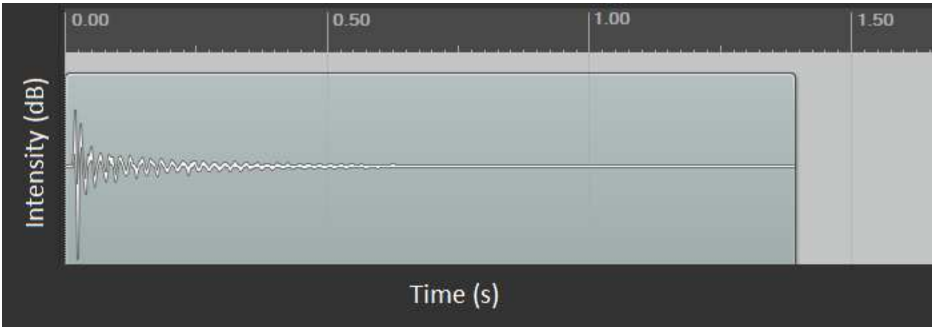


Figure 7.18. Sound’s envelope of the system with the resonant drumhead tuned at lower pitch than the batter drumhead

7.2.1. Discussion of results

If one looks to the envelope of the ideal bass drum sound (figure 7.12) it is seen that the objective is to find a configuration that generates a short sound (less than 0'25 seconds of duration) by strike. Observing resulting envelopes of three different resonant drumhead's configurations (or tunings) clearly appears one that can be the optimum: tuning C (resonant tuned at lower pitch than batter drumhead). Its envelope (figure 7.18) shows that in this configuration the bass drum's sound lasts a little more than 0'5 seconds whereas the other configurations' envelopes (A and B) reach 1 second of duration.

Comparing all three frequency spectrums (figures 7.13, 7.15 and 7.17) it is noticed that in the range between 700 and 7000 Hz the spectrums are very similar. Although the A configuration has higher levels at that range it has a similar shape as the other two. It can be easily deduced that the resonant drumhead's tuning has no (or minimum) effect on this range of the resulting system's sound. Then it is related to the batter drumhead. And as the batter drumhead is tuned at relatively low frequencies (range of 50 Hz) the frequency range between 700 and 7000 Hz must be related to the sound generated at the moment of the impact of the mace to the drumhead. This must be the reason that explains the similar shape of this range of frequencies.

However in the range between 15 and 200 Hz is where the resonant drumhead has a major effect. The A and B configuration's frequency spectrums have a prominent peak (at 70 Hz for A and at 60 Hz for B) that must be related to the resonant drumhead tuning. The difference between the peak and the tuning of both configurations is approximately the same (about 10 Hz higher than tunings). In C configuration's frequency spectrum, a peak (a discrete one) is found at about 50 Hz (13'5 Hz higher than its tuning). So these peaks may be related to an offset of the Drum Dial calibration with that value (about 10 to 13 Hz).

To see which configuration is closer to the desired result (ideal bass drum sound) is best comparing them directly. Next figures compare all three-frequency spectrum configurations (A, B and C) to the ideal bass drum's frequency spectrum (see figures 7.19, 7.20 and 7.21 shown below).

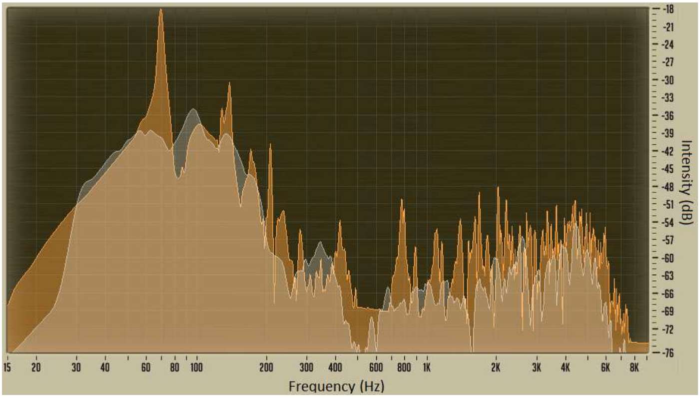


Figure 7.19. Comparison of frequency spectrums: ideal bass drum's sound (white) and A configuration (orange). (See appendix 1 for larger size).

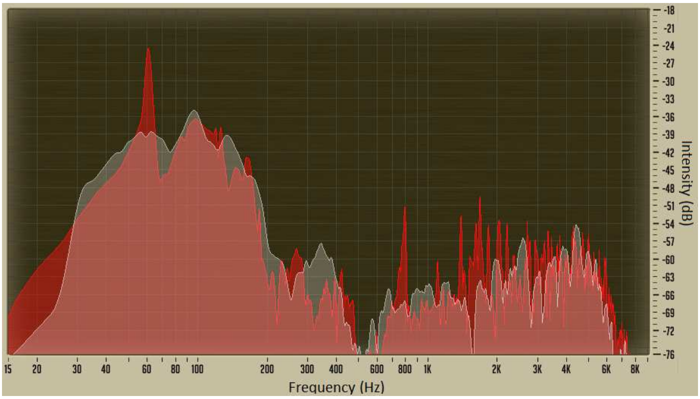


Figure 7.20. Comparison of frequency spectrums: ideal bass drum's sound (white) and B configuration (red). (See appendix 1 for larger size).

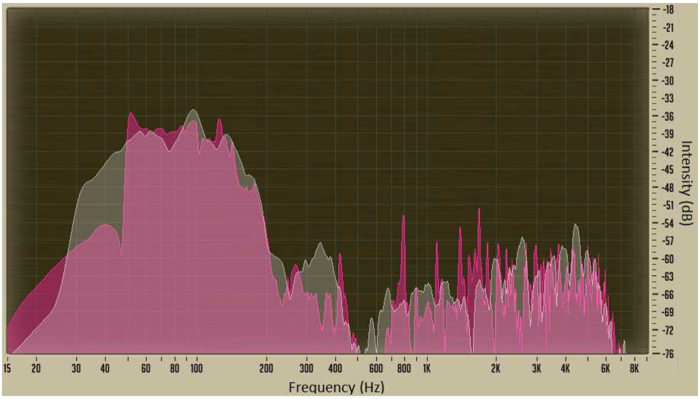


Figure 7.21. Comparison of frequency spectrums: ideal bass drum's sound (white) and C configuration (pink). (See appendix 1 for larger size).

As seen on these figures, shape of C configuration's frequency spectrum is closer to the ideal one. A and B frequency spectrum configurations have high peaks exceeding the ideal bass drum's sound frequency spectrum in the range between 15 and 500 Hz.

It is visible that as the resonant drumhead's tuning decreases the duration of the envelope decreases and frequency spectrums improves. So there is a relation between tension and sound quality for this system.

Still, there is further improvement to be made by modifying the frequency range between 700 to 7000 Hz. This will happen as the material improvement is applied.

7.3. MATERIAL SELECTION

According to acoustic needs next step was to make a material selection to modify the system's sound in the frequency range between 700 to 7000 Hz.

The frequency range mentioned is related to the sound generated at the moment that the mace impacts the batter drumhead. The sound focus is located at the center of the drumhead as the mace hits the center of it. Then sound waves propagate in all directions and they can be absorbed, reflected and/or transmitted through the materials. The sound captured by the microphone is the sum of direct sound and all sound reflected from the bass drum's shell inner surface to the microphone. The sound that can be heard outside the bass drum is the sum of the direct sound propagated outside and the sound transmitted through the bass drum's shell and drumheads.

It is possible to modify the sound produced by adding a material that absorbs an amount of it by damping. This project is focused to study the material improvement effect on the sound generated inside the bass drum with the microphone located as explained before.

The material selection problem approach will be as follows. A material that bends without failure is needed to fit inside of the bass drum. It needs to be light so it holds on glued to the surface without falling by gravity or by vibrations produced at playing the bass drum. It is needed to modify required frequencies to approach to desired sounds characteristics. And it is needed to be affordable to be a practicable solution for this problem.

So the problem has two clear approaches: according to mechanical properties and according to acoustic properties.

7.3.1. According to mechanical properties

The covering of the bass drum's inner area will be made with bended panels of damping material so this approach considers material needs as for an elastic hinge without failure.

Function: Light elastic hinge

Restriction: Hold a load without failing

Objective: Minimize mass

Free variables: Material selection and material thickness

7.3.1.1. Objective

Mass (needed to be minimized) of a panel can be calculated by:

$$m \leq A \cdot t \cdot \rho \quad \text{(eq. 7.3)}$$

Being *t* panel thickness, *A* panel area and ρ material relative density.

For an elastic hinge area deformation is given by:

$$\varepsilon = \frac{t}{2 \cdot R} \quad \text{(eq. 7.4)}$$

Being *R* the curvature radius (fixed by bass drum geometry).

As tension is given by:

$$\sigma = E \cdot \varepsilon \quad \text{(eq. 7.5)}$$

Being *E* the materials Young's modulus.

7.3.1.2. Restriction

$$\sigma \leq \sigma_{LE} \quad \text{(eq. 7.6)}$$

Being σ_{LE} yield strength.

Introducing (eq. 7.4) in (eq. 7.5) and restriction is obtained:

$$\sigma = E \cdot \frac{t}{2 \cdot R} \leq \sigma_{LE} \quad \text{(eq. 7.7)}$$

7.3.1.3. Free variable

$$t \leq \frac{\sigma_{LE} \cdot 2 \cdot R}{E} \quad \text{(eq. 7.8)}$$

Introducing (eq. 7.8) in (eq. 7.4) it is obtained:

$$m \leq A \cdot \frac{\sigma_{LE} \cdot 2 \cdot R}{E} \cdot \rho \quad \text{(eq. 7.9)}$$

Reorganizing (eq. 7.9) it is obtained:

$$m \leq A \cdot 2 \cdot R \cdot \frac{\sigma_{LE}}{E/\rho} \quad \text{(eq. 7.10)}$$

As *A* and *R* are fixed by the bass drum geometry they will be excluded from the material index. So the material index (which needs to be maximized) is:

$$M = \frac{E/\rho}{\sigma_{LE}} \quad \text{(eq. 7.11)}$$

7.3.1.4. Pre selection according to mechanical properties

To find possible candidates according to mechanical properties it is needed to work with corresponding Ashby's chart. From material index previously established (eq. 7.11) the following is obtained:

$$\log \sigma_{LE} = \log \frac{E}{\rho} - \log M \quad \text{(eq. 7.12)}$$

According to equation (eq. 7.12) the selection guideline will be made with a slope of value equal one. And as the material index needs to be maximized, all materials remaining below the guideline will be considered as possible choices for a mechanical properties selection. The ones which remain above the guideline won't.

Nowadays there are some materials sold as a solution for different acoustic needs. One of them (and very popular) is the Polyurethane foam conformed in panels.

Polyurethane foam (which its composition is (NH-R-NH-CO-O-R'-O-CO)n, R from a diisocyanate, R' from a polyol) is an elastomeric thermoset polymer. This foam, with a density between 20 and 30 kg/m^3, is commonly used for acoustic applications. Its minimum service temperature oscillates between -93 and -73ºC and its maximum between 67 and 77ºC. It also resists in wet ambient and is fair with UV radiation so it works well in ambient conditions.

It is used in some contexts as in recording studios or radios to absorb the incident sound to prevent its reflection (or an amount of it). There are different shapes (pyramidal, wedges and complex motives) and different sizes, according to the specific needs. It is an interesting candidate as it is an easy to find light and flexible material.

For these reasons the material index line will be located on polyurethane foam. The possible candidates will be discussed and if there is a better material than polyurethane foam for this problem it will be selected. Otherwise polyurethane foam will be the material that will be used to improve the system's sound.

The following Ashby's chart (Figure G.3.1) represents yield strength versus specific modulus (E/ρ).

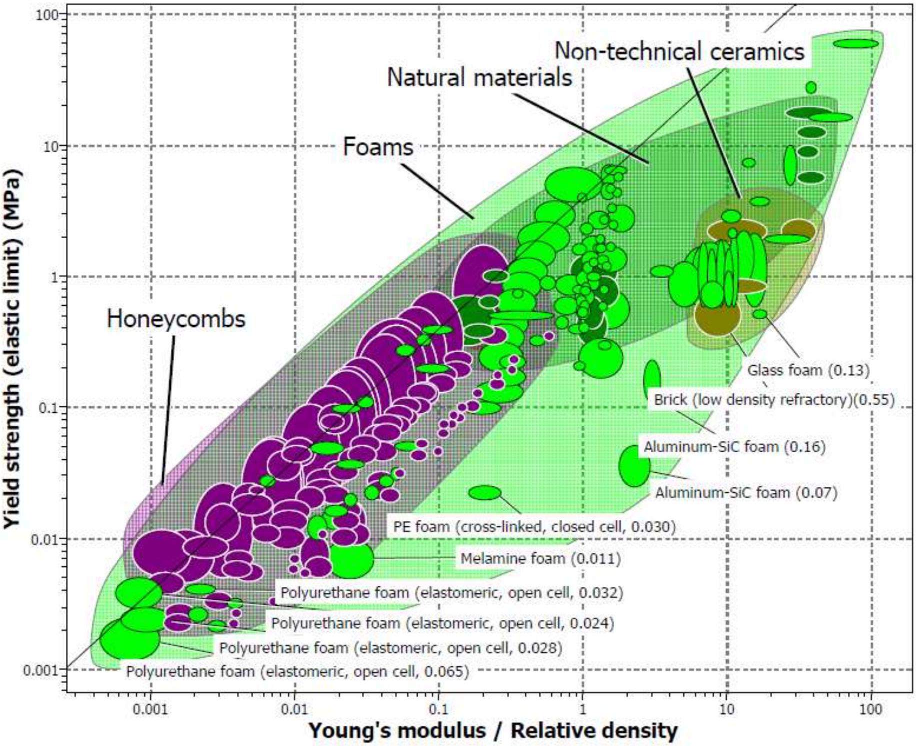


Figure 7.22. Yield strength vs. specific modulus.

As can be seen, there are some families as candidates for the selection such as foams (polyurethane, melamine, PE, Aluminum-Si, glass), honeycombs, natural materials and non-technical ceramics (brick). The ceramics family can be quickly discarded as they are rigid and fragile materials and they won't bend as it is needed and they won't absorb sound by damping. To make the proper material selection is best to proceed to make the selection according to acoustic properties and see if there is some coincidence.

7.3.2. According to acoustic properties

The material needs to modify the sound by damping and it also needs to be an affordable material.

Function: Sound absorption

Restriction: Ambient conditions resistant, geometry

Objective: Minimize cost and maximize sound damping

Free variables: Material selection

7.3.2.1. Objective 1

As usually acoustic treatment materials are sold by volume (pieces) for a minimization of cost per unit, volume calculation will be used,

$$C_V = C_m \cdot \rho \quad \text{(eq. 7.13)}$$

Being C_m cost per mass unit. The first material index for acoustic properties selection will be:

$$M_1 = C_m \cdot \rho \quad \text{(eq. 7.14)}$$

7.3.2.2. Objective 2

To absorb the incident sound waves it needs to be a material with a high damping coefficient (also called mechanical loss coefficient represented by η) or low acoustic brightness ($1/\eta$) which is the inverse of damping. As it needs to minimize acoustic brightness, the second material index for acoustic properties selection will be:

$$M_2 = \frac{1}{\eta} \quad \text{(eq. 7.15)}$$

7.3.2.3. Restriction

As a restriction, the material has to resist ambient conditions (service temperature between 0ºC and 35ºC, humidity and natural light) and be able of being produced in specific geometrical shape (as panels).

7.3.2.4. Free variable

Material selection is the free variable as it was mentioned before.

7.3.2.5. Pre selection according acoustic properties

Once the material indexes are defined one proceeds to work with corresponding Ashby's chart. Limitations needed will be used to specify properties not quantified but with a qualitative valuation.

The following Ashby's chart (figure G.3.2) represents acoustic brightness (or inverse of loss coefficient) versus cost per unit volume. For the needed acoustic properties it is clear that the foam family materials are the best choice followed by natural family materials. As it requires minimizing cost and acoustic brightness, best choices are those ones that are related to lower values of both axes.

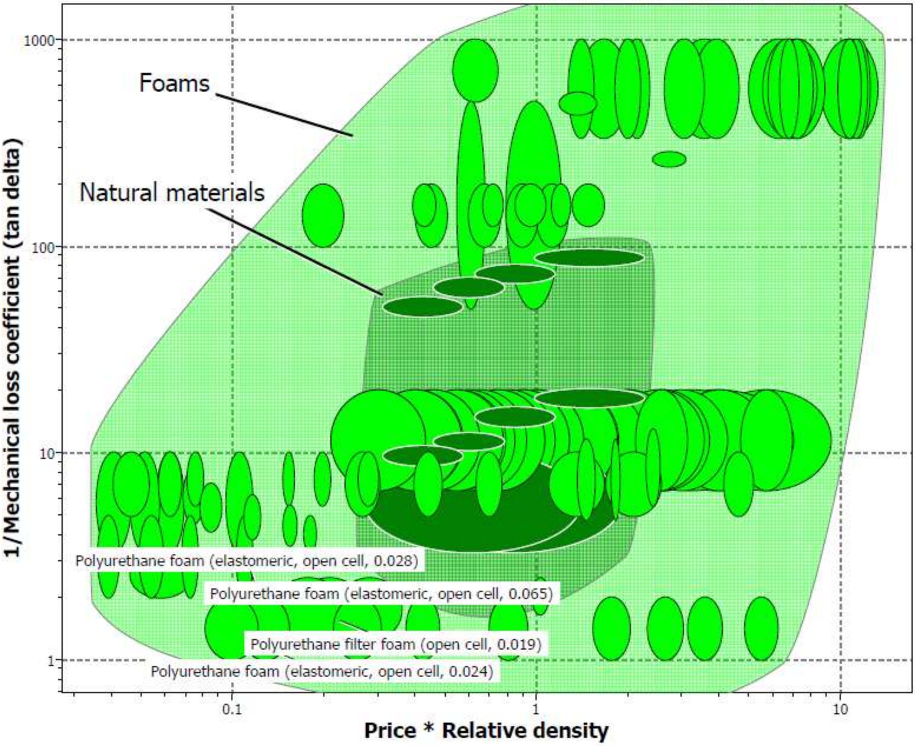


Figure 7.23. Acoustic brightness vs cost per unit volume.

Next chart (figure G.3.3) is a zoom in the selection zone (which is that related to low values of both axes) from the previous chart.. As it is clear the best choice is polyurethane foam with open cells with relative density values oscillating between 20 to 30 kg/m³.

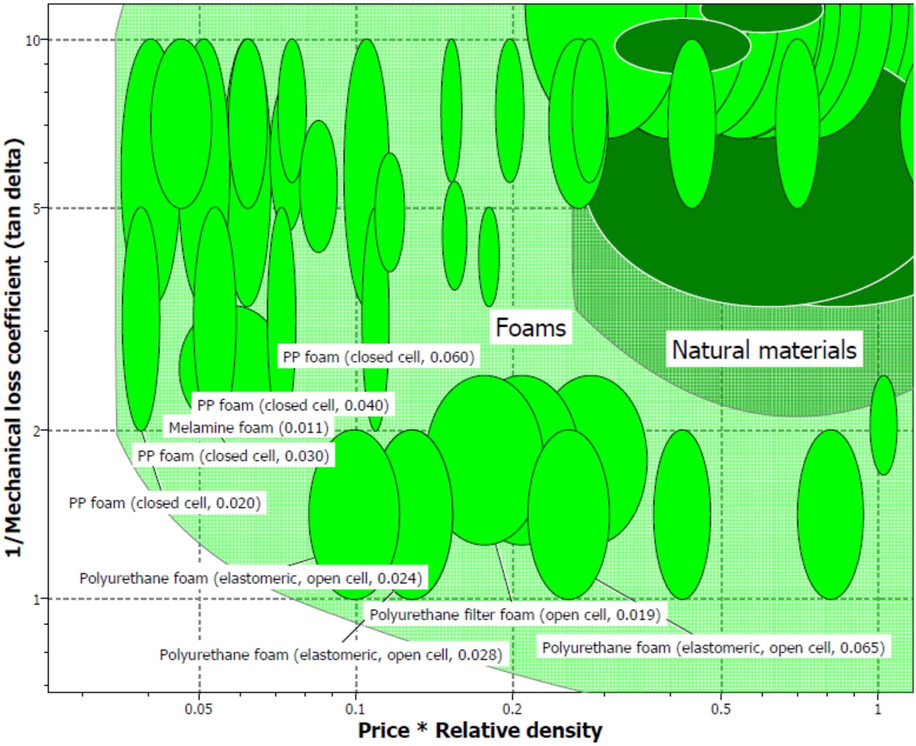


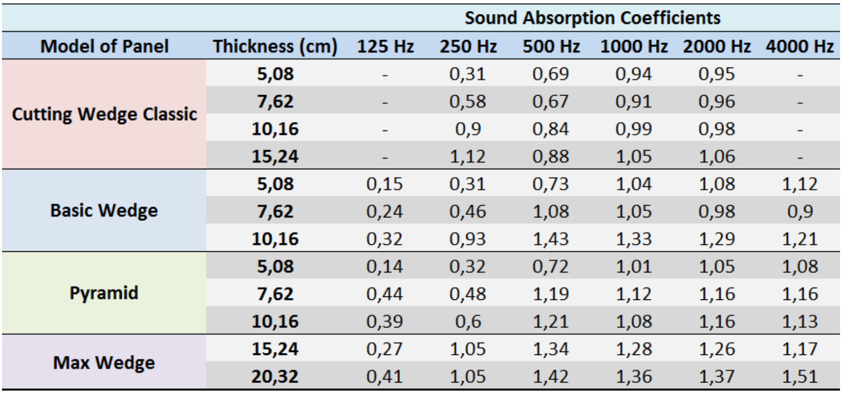
Figure 7.24. Zoom of acoustic brightness vs. cost per volume unit.

This is not strange as the needs are similar for a recording studio as for this system. In both cases there is a need for a material to absorb incident sound and prevent its reflection to be able to record a higher relation of direct sound to reflected sound. So the next step is finding the best shape of panel to apply to these needs.

7.3.3. Selecting Polyurethane foam panel

Once polyurethane foam with open cells is found to be the best solution to this problem, next step is finding the best panel pattern. To achieve it these different models need to be found and their properties compared. Next table (figure G.3.4) shows sound absorption coefficients for given frequencies for four different models in different panel's thickness. All of these models are made of Polyurethane foam with open cells with a density of 32 kg/m^3. This information and more can be found in a web store specialized in acoustic materials.

The model cutting wedge classic was discarded because there is no absorption defined in 4000 Hz. The material needs to absorb frequencies in the range between 700 and 7000 Hz. As the table gives sound absorption at these given frequencies, the model needed was one with higher values for 500 to 4000 Hz and lower values for 125 to 250 Hz.



		Sound Absorption Coefficients					
Model of Panel	**Thickness (cm)**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Cutting Wedge Classic	**5,08**	-	0,31	0,69	0,94	0,95	-
	7,62	-	0,58	0,67	0,91	0,96	-
	10,16	-	0,9	0,84	0,99	0,98	-
	15,24	-	1,12	0,88	1,05	1,06	-
Basic Wedge	**5,08**	0,15	0,31	0,73	1,04	1,08	1,12
	7,62	0,24	0,46	1,08	1,05	0,98	0,9
	10,16	0,32	0,93	1,43	1,33	1,29	1,21
Pyramid	**5,08**	0,14	0,32	0,72	1,01	1,05	1,08
	7,62	0,44	0,48	1,19	1,12	1,16	1,16
	10,16	0,39	0,6	1,21	1,08	1,16	1,13
Max Wedge	**15,24**	0,27	1,05	1,34	1,28	1,26	1,17
	20,32	0,41	1,05	1,42	1,36	1,37	1,51

Figure 7.25. Sound absorption coefficients of four models of polyurethane foam [9].

The Max Wedge model was also discarded as it has too high absorption coefficient values for 250 Hz. Pyramid models of 5’08 cm and 7’62 cm of thickness were good candidates as the values of sound absorption coefficient at 125 to 250 Hz are low and at 500 to 4000 Hz are higher and constant (more the 7’62 cm of thickness model). Basic Wedge models’ absorption coefficient values are less constant in the range is needed so they were discarded. The best choice was the Pyramid model in 7’62 cm thickness.

Next step was to find this material and apply it to the system. A Pyramid model of polyurethane foam panel with 6 cm of thickness was found (the closest model available) so it was the material used for next experimentations.

7.4. ACOUSTIC MATERIAL IMPROVEMENT (POLYURETHANE FOAM WITH OPEN CELLS)

Next figure (figure 7.26) shows the effect of material improvement on the sound system's envelope:

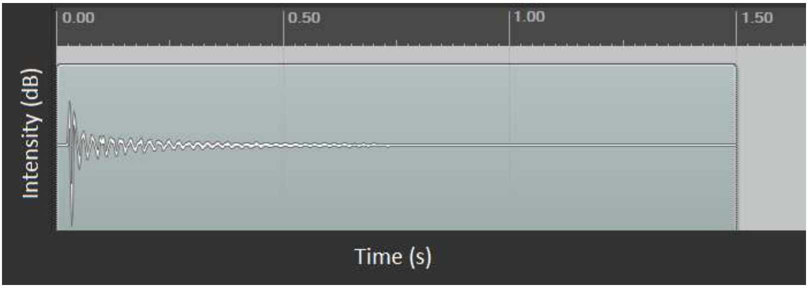


Figure 7.26. Sound's envelope of the system with the resonant drumhead tuned at lower pitch than the batter with 50% of inner area treated.

Compared to sound's envelope of the untreated system (figure 7.18):

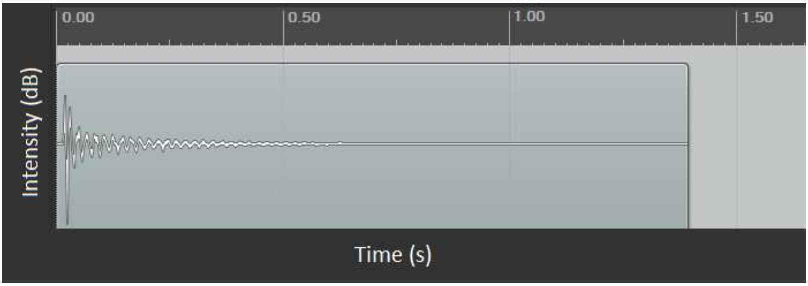


Figure 7.18. Sound's envelope of the system with the resonant drumhead tuned at lower pitch than the batter.

As seen in the figures, there is no substantial effect on the sound's envelope with the material improvement. They have practically the same shape and duration.

Then the frequency spectrums of treated system need to be discussed, to evaluate the effect of the material used in this project (polyurethane foams with open cells panels with pyramidal pattern). To do so, it needs to be compared to the untreated frequency spectrum.

Next figure (figure G.4.2) compares the C configuration to the same C configuration with 50% of inner area treated with polyurethane foam panels:

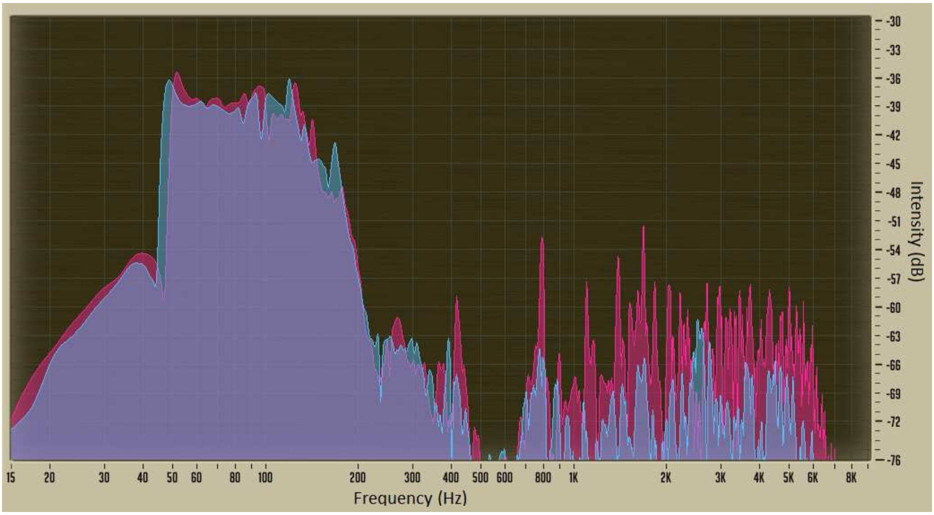


Figure 7.27. Comparison of frequency spectrums: untreated C configuration (pink) with 50% area treated C configuration (blue)

As seen in the figure, there is an important reduction of intensity level (from 6 to 13 dB) in the range between 700 and 7000 Hz. This intensity reduction is the consequence of the absorption of part of the sound that was supposed to be reflected by bass drum's inner area to the microphone. As 50% of the area is treated one must think that with less amount of area treated lesser will be the intensity reduction.

The zone between 15 and 300 Hz can be considered unaffected by the material improvement. There is a minimum discrepancy between these shapes but can be related to a little difference of tuning as the system was needed to be dismounted to glue the polyurethane panels and be mounted again.

It is a clear effect of the material improvement at the range of frequencies that was needed.

To see if the objective is achieved, the resulting frequency spectrum of this material improvement will be compared to the ideal sound's frequency spectrum.

Next figure (figure G.4.3) compares the ideal bass drum's sound frequency spectrum to C configuration with 50% of inner area treated with polyurethane foam panels.

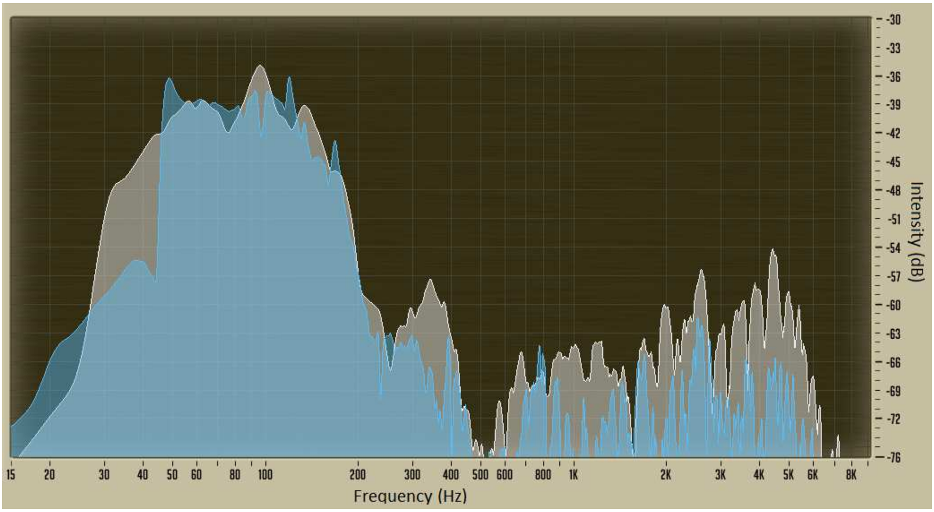


Figure 7.28. Comparison of frequency spectrums: ideal bass drum's sound (white) with 50% of inner area treated C configuration (blue).

As it is seen in this figure, the objective is achieved: to reduce the intensity in frequency range between 700 and 7000 Hz with the application of the material previously selected. Although the reduction is achieved still there is a little spike on 800 Hz that exceeds (about 3 dB) the ideal frequency spectrum at that point. Except for that spike, there is even more intensity reduction than expected in frequency range between 900 and 7000 Hz. So the next experimentations were made trying to reduce the amount of area treated to know if is possible a better adjust to the ideal bass drum's sound frequency spectrum.

Figures shown in next page show the frequency spectrum comparisons between the ideal bass drum's sound and the C's configuration with 37'5% of inner area treated (figure G.4.4) and with 25% of inner area treated (figure G.4.5).

As it is seen on the figures, treating lesser area involves changes in the resulting sound. The range more affected by removing material on the inner area of the bass drum is around 800 Hz (see the spike that stands there).

If one looks to the ideal's bass drum sound's frequency spectrum (white) at range from 600 to 6000 Hz it is seen that the shape which needs to be achieved, is one that increases along of that frequency range.

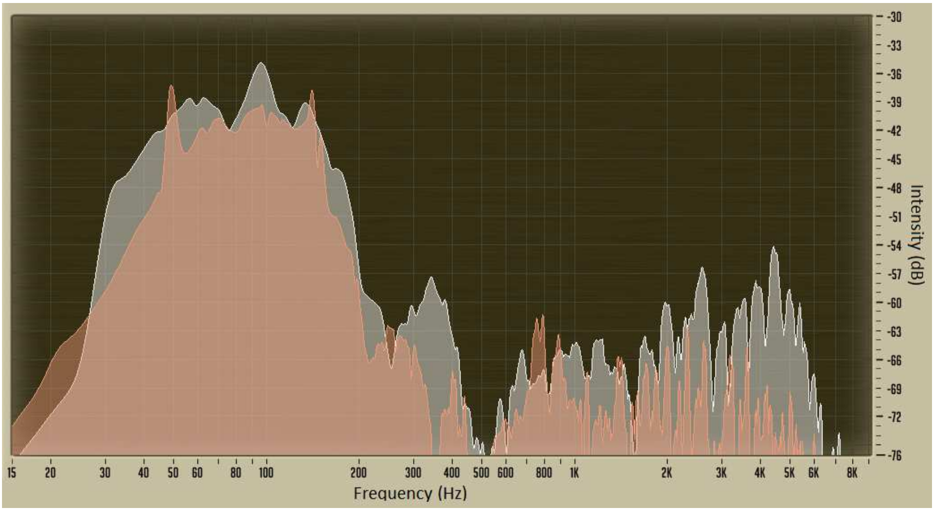


Figure 7.29. Comparison of frequency spectrums: ideal bass drum's sound (white) with 37'5% of inner area treated C configuration (pale orange).

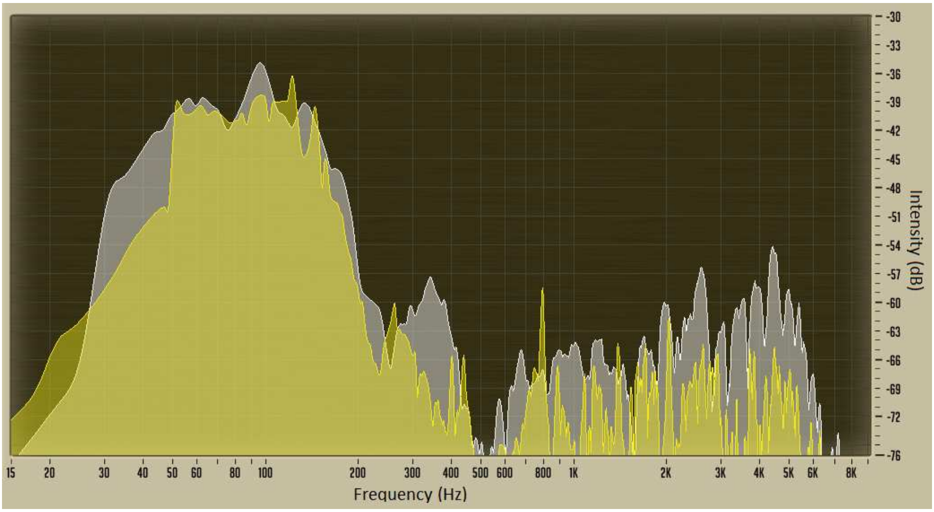


Figure 7.30. Comparison of frequency spectrums: ideal bass drum's sound (white) with 37'5% of inner area treated C configuration (yellow).

Comparing the range from 600 to 6000 Hz of all three frequency spectrums of treated systems (figures G.4.3, G.4.4 and G.4.5, also in appendix 1 for easier comparison) it can be observed that at lesser material covering bass drum's inner area, lesser is the resemblance to the ideal shape that is wanted to achieve.

8. CONCLUSIONS

- There is a relation between membranes' tension and system's sound quality. For a batter drumhead equitably tensed at a given tension (directly related to tune) the sound improves when decreasing tension of the resonant drumhead. Best results are when resonant drumhead's tuning is below the batter drumhead's tuning.
- Polyurethane foam (with open cells) panels with pyramid pattern, found in specialized stores as acoustic materials, are a good solution to improve the sound quality for this system's needs. Applied to the bass drum's inner area this material modifies its sound in its medium and high frequency range (700 to 7000 Hz) by absorption.

In conclusion both improvements studied in this project result in a bass drum's sound closer to an ideal for acoustic situations in which there are no device improvement possible (as equalization for example). It would even be possible to apply them to a studio session or a live performance and thereby make the sound engineer's work easier.

9. REFERENCES AND NOTES

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8. Free downloading of SPAN in: http://www.voxengo.com/product/span/
9. Products information in: www.acousticsfirst.com

APPENDICES

APPENDIX 1: FREQUENCY SPECTRUMS

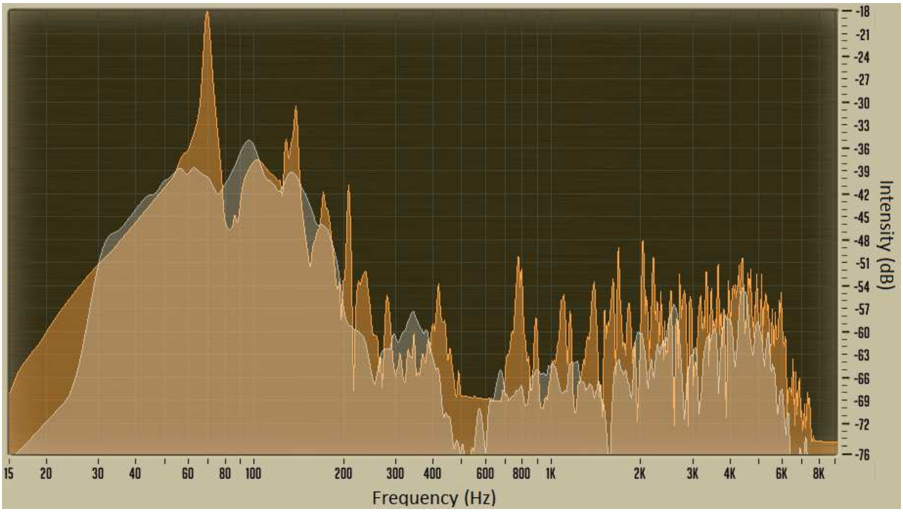

Figure 7.19. Comparison of frequency spectrums: ideal bass drum's sound (white) and A configuration (orange).

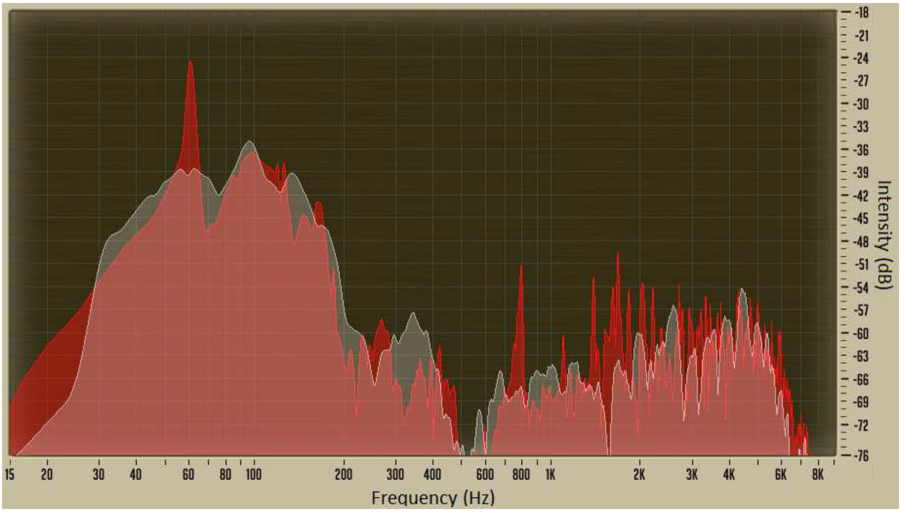

Figure 7.20. Comparison of frequency spectrums: ideal bass drum's sound (white) and B configuration (red).

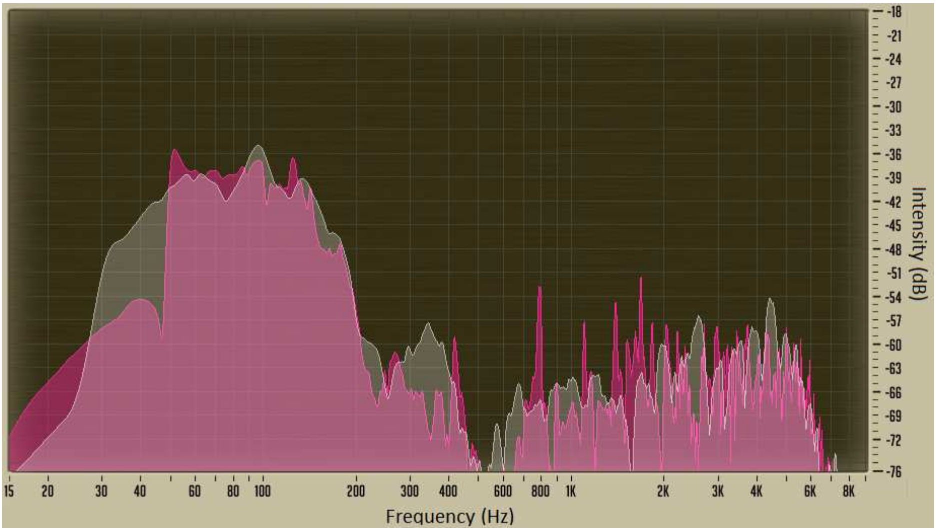

Figure 7.21. Comparison of frequency spectrums: ideal bass drum's sound (white) and C configuration (pink).

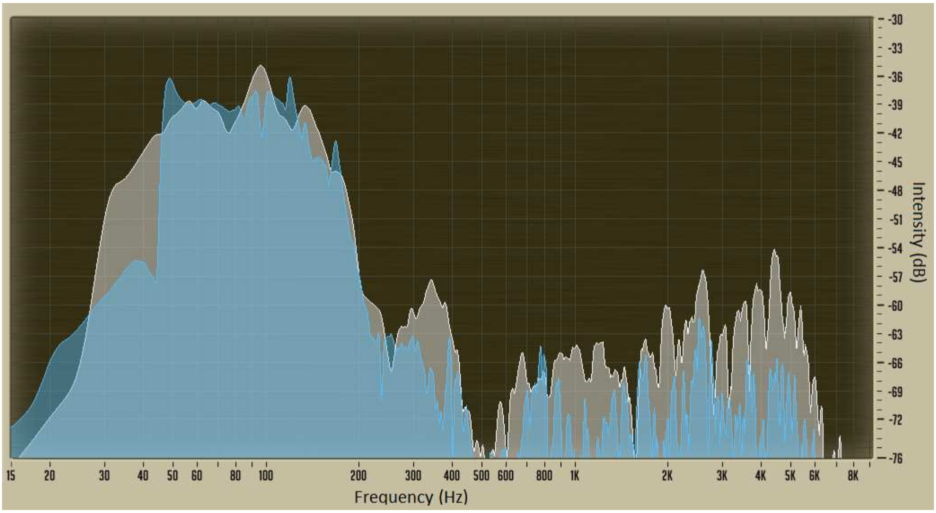

Figure 7.28. Comparison of frequency spectrums: ideal bass drum's sound (white) with 50% of inner area treated C configuration (blue).

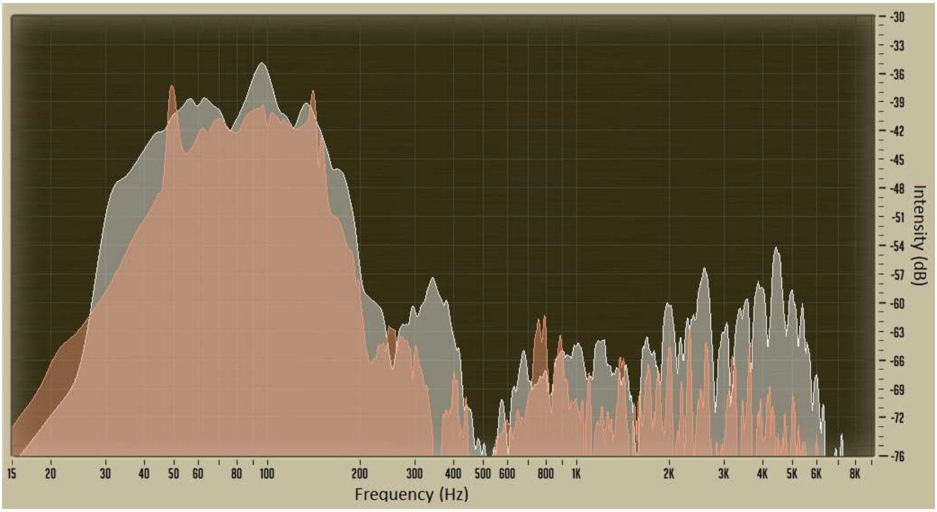

Figure 7.29. Comparison of frequency spectrums: ideal bass drum's sound (white) with 37'5% of inner area treated C configuration (pale orange).

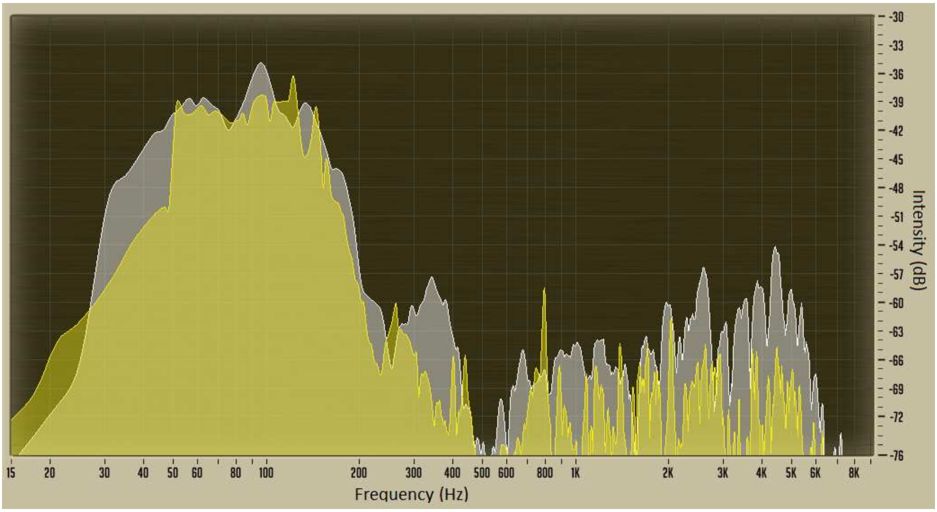

Figure 7.30. Comparison of frequency spectrums: ideal bass drum's sound (white) with 37'5% of inner area treated C configuration (yellow).