CHAPTER 5

SIMULATION USING ODEON

5.1 GENERAL INTRODUCTION

This chapter deals with the sound transmission loss performance of block walls and panel using ODEON. This package was developed on the basis of vibro acoustic predictive behavior between the structure and fluid. Theoretical problems are not realistic in the sense that, the assumptions implied to obtain a closed-form analytical solution make the mathematical model to deviate from the real life situation. A wave model for sound propagation leads to more or less efficient methods for solving a wave equation, like the Finite Element Method (RAY TRACING) and Boundary Element Method (BEM). Wave models are characterised by creating very accurate results at single frequencies. The number of natural modes in a room increases with the third power of the frequency, which means that for practical use wave models are restricted to low frequencies. Hence Ray tracing model imposing the conditions of sound propagation requires more effort to duplicate the theoretical result that would be required to solve the real world problem.

The average value in frequency bands, being either octave or one-third-octave bands, have been more relevant in geometrical room acoustics. The statistical room acoustics implies treating the sound pressure in a room as a stochastic quantity with a certain space variance. The classical diffuse field model, also called the Sabine model, is an extreme case in this respect, “reverberation” is
still being frequently used. In a diffuse field model, the space variance of the sound pressure is zero, the energy density is everywhere the same in the room.

For the simulation of sound in rooms there are two geometrical methods, namely ray tracing and the image source method. For both methods the wavelength and the frequency of the sound is not inherent in the model. As the wave front moves in time, the line described in space by a given point on the surface is called the ray path. In room acoustics they assume that the amplitude is constant over the wave front or that the wave front is a plane surface. Curved paths have no place in geometrical room acoustics; the sound energy propagates along straight ray paths just like light. Inherent in these geometrical models there is no frequency information and the validity of the calculated results is in principle limited to a frequency range where we may assume specular reflections and even diffraction phenomena may be neglected. Such phenomena may, however, be included in these models by certain artifices. This means the geometrical models tend to create high order reflections, which are more accurate with the real sound wave propagation. The pure geometrical models are limited to low order deflections and hence it is a need to consider the scattering coefficient to the surface. In this way the reflection from a surface has been modified into pure specular behavior of sound in computer simulation model. The acoustic Ray Tracing method has been used to evaluate resonance frequencies and corresponding pressure distribution.

5.1.1 Ray Tracing Method Applied to Acoustics

Ray tracing methods is done by finding propagation paths between a source and receiver by generating rays emanating from the source position and following them through the environment until a set of rays has been found that reach the receiver. The primary advantage of these methods is their simplicity. They depend only on ray–surface intersection calculations, which are relatively easy to
implement and have computational complexity that grows sublinearly with the number of surfaces in the model. Another advantage is generality. As each ray–surface intersection is found, paths of specular diffuse reflection, diffraction, and refraction has been sampled thereby modelling arbitrary types of propagation, even for models with curved surfaces. The primary disadvantages of ray tracing methods stem from their discrete sampling of rays, which may lead to under sampling errors in predicted room responses.

The Ray Tracing Method uses a large number of particles, which are emitted in various directions from a source point. The particles are traced around the room loosing energy at each reflection according to the absorption coefficient of the surface. When a particle hits a surface it is reflected, which means that a new direction of propagation is determined. This is called a specular reflection. In order to obtain a calculation result related to a specific receiver position it is necessary either to define an area or a volume around the receiver in order to catch the particles when travelling by, or the sound rays may be considered as the axis of a wedge or pyramid. In any case there is a risk of collecting false reflections and moreover some possible reflection paths are not found. There is a reasonable high probability that a ray will discover a surface with the area A after having travelled the time t if the area of the wave front per ray is not larger than A/2.

This leads to the minimum number of rays

\[ N \geq \frac{8\pi c^2}{A} t^2 \]  

(5.1)

Where,

\( c \) is the speed of sound in air
\( A \) the surface area,
\( t \) Time sound travelled.
5.1.2 Image Source Method

The image source method is based on the principle, that a specular reflection has been constructed geometrically by mirroring the source in the plane of the reflecting surface. In a rectangular box-shaped room it is very simple to construct all image sources up to a certain order of reflection, and from this it is found that if the volume of the room is \( V \), the approximate number of image sources within a radius of \( ct \) is

\[
N_{\text{refl}} = \frac{4 \pi c^3}{3 V t^3}
\]  

(5.2)

This is an estimate of the number of reflections that will arrive at a receiver up to the time \( t \) after sound emission, and statistically this equation holds for any room geometry. In a typical auditorium there is often a higher density of early reflections, but this will be compensated by fewer late reflections, so that the average number of reflections increases with time in the third power.

The advantage of the image source method is that it is very accurate, but a problem occurs when room is not a simple rectangular. With \( n \) surfaces there will be \( n \) possible image sources of first order and each of these create \((n - 1)\) second order image sources. Up to the reflection order \( i \) the number of possible image sources \( N_{\text{sou}} \) will be

\[
N_{\text{sou}} = 1 + \frac{n}{(n - 2)}((n - 1)^i - 1) \approx (n - 1)^i
\]  

(5.3)
5.1.3 Hybrid Method

The disadvantages of the two classical methods have lead to the development of hybrid models, which combine the best features of both methods [85, 86, 87]. The idea is that an efficient way to find image sources having high probabilities of being valid is to trace rays from the source and note the surfaces they hit. The reflection sequences thus generated are then tested as to whether they contribute at the chosen receiver position. This is called a visibility test and it has been performed as a tracing back from the receiver towards the image source. This leads to a sequence of reflections, which must be the reverse of the sequence of reflecting walls creating the image source. Once 'backtracing' has found an image to be valid, then the level of the corresponding reflection is simply the product of the energy reflection coefficients of the walls involved and the level of the source in the relevant direction of radiation. The distance to the image source gives the arrival time of the reflection.

It is, of course, common for more than one ray to follow the same sequence of surfaces, and discover the same potentially valid images. It is necessary to ensure that each valid image is only accepted once; otherwise duplicate reflections would appear in the reflectogram and cause errors. Therefore it is necessary to keep track of the early reflection images found, by building an 'image tree'.

For a given image source to be discovered, it is necessary for at least one ray to follow the sequence which define it. The finite number of rays used places an upper limit on the length of accurate reflectogram obtainable. Thereafter, some other method has to be used to generate a reverberation tail. This part of the task is the focus of much effort, and numerous approaches have been suggested, usually based on statistical properties of the room's geometry and absorption. One method,
which has proven to be efficient, is the 'secondary source' method used in the ODEON program [87]. This method is outlined in the following paragraph below.

After the transition from early to late reflections, the rays are treated as carriers of energy rather than explorers of the geometry. Each time a ray hits a surface, a secondary source is generated at the collision point. The energy of the secondary source is the total energy of the primary source divided by the number of rays and multiplied by the reflection coefficients of the surfaces involved in the ray's history up to that point. Each secondary source is considered to radiate into a hemisphere as an elemental area radiator. Thus the intensity is proportional to the cosine of the angle between the surface normal and the vector from the secondary source to the receiver.

The intensity of the reflection at the receiver also falls according to the inverse square law, with the secondary source position as the origin. The time of arrival of a reflection is determined by the sum of the path lengths from the primary source to the secondary source via intermediate reflecting surfaces and the distance from the secondary source to the receiver. As for the early reflections a visibility test is made to ensure that a secondary source only contributes a reflection if it is visible from the receiver. Thus the late reflections are specific to a certain receiver position and it is possible to take shielding and convex room shapes into account. In the figure 5.1, two neighbouring rays are followed up to the sixth reflection order. The first two reflections are specular, and both rays find the image sources S1. The image sources gives rise to one reflection each in the response, since they are visible from the receiver point R. The advantage of Hybrid method is that it solve simultaneously the internal and external acoustic radiation problems simultaneously.
In the hybrid model it is a critical point at which reflection order the transition is made from early to late reflections. Since the early reflections are determined more accurately than the late reflections one might think that better results are obtained with the transition order as high as possible. However, for a given number of rays the chance of missing some images increases with reflection order and with the number of small surfaces in the room.

The probability of an image being visible from the receiver decreases with the size of the surfaces taking part in its generation, so the number of reflections missed due to insufficient rays will be much fewer than the number of potential images missed. Secondly, in real life, reflections from small surfaces are generally much weaker than calculated by the laws of geometrical acoustics, so any such reflections missed by the model are in reality of less significance than the model itself would suggest. Actually, the efforts of an extended calculation may lead to worse results. This means that a hybrid model give better results than both of the pure basic methods and with much shorter calculation time. This phenomenon is closely related to the introduction of diffusion in the model.

5.2 ODEON APPLICATION

The room acoustic modeling software ODEON is based on ray tracing in combination with a secondary source radiation method for reflections after a certain transition order, typically 0 – 3 order of reflection. In version 10.0 of this software the option of sound transmission modeling has been introduced [87]. The method is particularly useful for the prediction of sound insulation between spaces with non-diffuse sound fields like rooms with very uneven distribution of sound absorption and/or special room shape. The analytical aspects of transmission loss suite with the samples, transmission loss have been studied using ODEON. This package has a
multi-model architecture to combine an acoustic finite element model with a direct boundary element model, or at times combine multiple direct boundary element models into a larger super-model. The acoustic model is coupled to structural Finite element model to represent interaction effect between vibrating structures and the acoustic medium. The computer model using ODEON is fast, typically a new set of results are available a few hours after some changes to the model have been proposed. But the advantages are not restricted to time and costs. The most important advantage is probably that the results has been visualised and analysed much better because a computer model contains more information than a set of measurements done in a scale model with small microphones.

The reflectogram displays the arrival of early reflections to a receiver. When the early reflections are calculated from detected image sources, it follows that each single reflection has been separated independently. In addition to arrival time and energy of the reflection, it is also possible to get information about the direction and which surfaces are involved in the reflection path. Figure. 5.1 shows the schematic form how the calculation model behaves.

The reflection paths for all early reflections has been visualised in 3D and analysed in detail. During the design of a room it is useful to see which surfaces are active in creating the early reflections. Although it is difficult to extract specific results from such a spatial analysis, and it helps to understand how a room responds to sound.

To calculate the response at a large number of receivers distributed in a grid that covers the audience area. It is needed to view a mapping of the spatial distribution of acoustical parameters. Uneven sound distribution and acoustically
weak spots could easily be localised and appropriate countermeasures could be taken.

The auralisation technique offers the possibility to use the ears and listen to the acoustics of a room already during the design process. Several acoustical problems in a room have easily been detected with the ears, whereas they may be difficult to express with a parameter that has been calculated. In principle it is possible to use impulse responses measured in a scale model for auralisation. However, the quality may suffer seriously due to non-ideal transducers. The transducers are one reason that the Odeon model is superior for auralisation. Another reason is that the information about each reflection's direction of arrival allows a more sophisticated modelling of the listener's head-related transfer function.

The auralisation options available in the ODEON program is based on binaural technology allowing three-dimensional presentation of the predicted acoustics over headphones. In the receiver point the BRIR (Binaural Room Impulse Response) is calculated. This is a pair of impulse responses, one for each ear of a listening person with the head in the receiver position. The listening signal is an anechoic recording, which could be speech, song, music, hand clapping or whatever could be relevant for a listening test. This anechoic signal is brought into the room by a convolution of the signal with the calculated BRIR.
All calculations including the ray tracing, received reflections at a receiver point, binaural filtering and convolution are carried out by ODEON in a one step process, so that there is no need for pre or post processing. The binaural filtering is highly optimised and includes complete room and binaural filtering of each reflection. Full filtering is essential for a high quality auralisation that allows simulation of special room acoustic effects like coupled rooms, frequency dependent reverberation etc. Typical 10,000 – 100,000 reflections are used, and the sampling frequency is 44.1 kHz. Calculation time is approximately 20 seconds for creating the BRIR, and the time for the convolution is approximately the same as the length of the signal on a computer with 600 MHz clock frequency.

In a complete calculation the last early reflection (from an image source) will typically arrive after the first late reflection (from a secondary source), so there will be a time interval where the two methods overlap. This is indicated on the
calculated energy response curve in Figure. 5.2. Also shown is the decay curve, which is the reverse-integrated impulse response. This is used for calculation of reverberation time and other room acoustical parameters. Figure 5.3 shows the calculated reverberation time.

5.2.1. General modeling details

In order to study a room in ODEON, a file containing the description of the room’s geometry has been created. The geometry model file could be created by typing the model data directly into a text file in the supplied text editor OdeonEdit. Even though the ODEON package is mainly meant for the acoustical analysis, it is complicated to create 3D models using OdeonEdit and geometrical parameters. To make the work easier the 3d models is been created using Cad drawing tools. The structural models of structures has been developed in these packages and imported to ODEON in DXF (Drawing eXchage Format) formats which is been extruded in to parametric language in OdeonEdit. The models created using other CAD entities must be the surface models defined from planar surface. Any block in a drawing which contains relevant 3D surface data must be exploded using the EXPLODE command before exported to the DXF file. It is important that the correct unit in which the geometry is modelled is selected in the import dialog. If the correct unit is not specified the import process may fail because the geometry will be smaller than the actual model. Figure 5.4 shows the model of testing facility developed in ODEON packages.
Figure 5.2. Energy response curve and decay curve calculated.

Figure 5.3. Reverberation time of testing Facility calculated using ODEON.
All surfaces in Odeon should be planar, so the curved surfaces have been approximated by dividing them into small plane sections. Using many surfaces in the model will:

- Make the model visually complex, and increase the probability of errors in the model, typically small leaks may become a problem.
- Not combine with the image source theory used for the early reflections (point sources).
- Increase the calculation time.

In order to calculate focusing from concave surfaces, the wall type of surfaces forming a concave shape should be set to fractional in the Materials List otherwise the concave surface will scatter sound too much, taking into account the small areas of the individual surfaces forming the concave shape - rather than the total area of the concave shape. The Reflection based scattering method would produce too much scattering in this case.

Subdivisions about every $10^\circ$ to $30^\circ$ will probably be adequate to reproduce focussing trends, without excessive number of surfaces, thus walls in a cylindrical room may be modelled from 12 to 36 surfaces. A cylindrical column which disperses energy may probably be modelled from, say 6 to 8 surfaces. The acoustical analysis is carried out by ODEON for the developed structural model of the acoustical transmission loss suite.
The enclosure model is studied through ODEON to obtain the natural frequencies of the structure. The RAY TRACING analysis must be an accurate model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions and other features that are used to represent the physical system.
The term ‘model generation’ usually takes on the narrower meaning of generating the nodes and elements that represent spatial volume and connectivity of the actual system. The various types involving in the generation of the model are as follows:

- Determining the objectives, choosing the appropriate element types, and approximating the mesh density of choice.
- Model-building using solid modeling procedures.
- Establishing a work plane such as the distance and other spatial coordinates.
- Generating basic geometric features. Activate the appropriate coordinate system such as different panel samples involved in the study.
- Generating other solid model features from the bottom up. That is, create key points, and then define lines, areas, and volumes as needed.
- Creating tables of element attributes (element types, real constants, material properties, and element coordinate systems).
- Setting element attribute pointers.
- Setting meshing controls to establish the desired mesh density.
- Creating nodes and elements by meshing the solid model.
- After generating nodes and elements, features such as surface-to-surface contact elements, coupled degrees of freedom and constraint equations are added if required.
- The models could also done using 3d models software like autocadd and revit in .dx formats and extracted the coordinates of models in ODEON.

With these objectives an transmission loss suite with two rooms as of in experimental study with the test opening is developed, with 2.1 x 3 m panels. The model considered in this work has been treated as a coupled problem, with the interaction between fluid and structure. Other aspects such as resonance, acoustical leakages are also considered. The model is discretized and structural frequencies
and TL suite frequencies are studied. This structural model component is coupled with the acoustical model for further study.

5.3 ENCLOSURE MESH FORMATION

The structure is discretized using four noded solid brick isoparametric element with each node having three degrees of freedom. According to the model dimensions totally 20,000 nodes are existing in the structure. The important criteria in discretization is related to the frequency for which there are six elements per wavelength, i.e., length is equal to one-sixth of the wavelength, for the given fluid associated with the element.

Sound source is defined at the centre of the source room and an input sound pressure of 100dB is given in the source room. The corresponding levels in the receiver room are computed by one meter away from the panel in the receiver room. The panel behaviour is studied and their transmission loss is estimated in the frequency range of 63-4000Hz. Properties of the material (ferrocement, Hollow block) like the density, Young’s modulus, loss factor were applied for calculating the transmission loss. An admittance value of 0.01 has been given.

Modal frequencies for the materials are calculated and are shown in the Tables 5.1, 5.2, and 5.3. which gives the modal frequency analysis of Hollow blocks, ferrocement panel. Pressure variations with respect to different frequencies in steps of 20 have been computed. Figure 5.5 shows sound levels of impulse response of source and receiver room using Odeon. Figure 5.6 shows the auralisation of right ear and left ear impulse responses in source room. Figure 5.7 shows the pressure variation of coconut shell hollow block. Figures 5.7 - 5.34 shows the pressure variations of hollow blocks and ferrocement panels. From the
figure 5.7 it is seen that pressure variations gradually increase with the increase in frequency and reduces at a frequency of 160Hz this is due to the panel resonance behavior. Figures 5.7 - 5.27 shows the pressure variation of coconut shell hollow blocks, it is seen that the pressure variations are concentrated in a similar way like that of the normal hollow block walls.

Figure 5.5. Impulse response of source and receiver room of coconut shell hollow block calculated using ODEON.
Figure 5.6. Auralisation of Impulse response inside source room calculated using ODEON.

Figure 5.7. Sound pressure levels of receiver room when coconut shell hollow block is considered in the openings.
Transmission loss of the material is computed based on the pressure levels. Table 5.4 shows the comparison between the measured and predicted values using ODEON. It is seen that there is a difference of 5-10dB between the measured and predicted values using ODEON.

5.4 RESULTS FROM THE ANALYSIS

Limited studies in the following cases using ODEON have been conducted through this methodology.

i) Coconut shell hollow blocks
ii) Coconut shell impregnated Ferrocement panels
iii) Coconut fibre impregnated panel with cavity
iv) Coconut fibre impregnated panel with cavity insulation of high density fibre glass wool of 50mm thick (48kg/m³)

5.4.1 Coconut shell hollow blocks

Hollow block wall is taken for the analysis of transmission loss. The structural frequencies of the panel solved through ODEON are shown in table 5.1. The transmission loss evaluation is done by calculating the transmission at 1m from the wall on the receiver room side for three points. The pressure variations and sound pressure level distributions on the Hollow blocks are shown in the Figures 4.19 to 4.30. The pressure variation is more in the lower frequency and decreases at the frequency of 140Hz and further increases at 200Hz.
Table 5.1 Structural Modal Frequencies for Hollow Blocks

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Modal Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26.1</td>
</tr>
<tr>
<td>2</td>
<td>52.7</td>
</tr>
<tr>
<td>3</td>
<td>52.7</td>
</tr>
<tr>
<td>4</td>
<td>71.6</td>
</tr>
</tbody>
</table>

5.4.2 Coconut fibre impregnated ferrocement panels

The modal frequencies for the ferrocement panel are obtained and the first four modes are shown in table 5.30. The field point pressure or jump pressure levels of the ferrocement panel for different frequency regions have been evaluated. Figures 4.30-4.35 shows the field point pressure or jump pressure levels for different frequency ranges. It is seen that the pressure levels increases at the center of the room and decreases along the edges of the rooms. The transmission loss is more at low frequency regions of 20-60Hz and decreases at 80Hz and again increases at the region 160Hz. This could be due to the panel resonance behaviour.

Table 5.2 Structural Modal Frequencies for Ferrocement panels

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Modal Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37.7</td>
</tr>
<tr>
<td>2</td>
<td>77</td>
</tr>
<tr>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>4</td>
<td>110</td>
</tr>
</tbody>
</table>
5.4.3 Coconut fibre impregnated ferrocement panels with cavity

In this case the cavity system with two panels with an airgap of 20mm is designed. The transparency coefficient of cavity is calculated and values are assigned in ODEON simulation. Table 5.3 shows the comparative results of ODEON simulation and experimental results. It is seen that the dips occur at 125Hz in the low frequency region, because of the presence of cavity insulation, the dips are more predominant in the low frequency region, whereas it is not so in the other two cases. At high frequency regions critical frequency dips occur at 1000-2000Hz. This reduction in power transmission is due to the size and thickness of the plate and also due to the air-cavity coupling that plays a major part in energy transmission.

5.4.4 Coconut fibre impregnated ferrocement panel with cavity insulation

In this case the cavity system with two panels with an airgap of 50mm is constructed and filled with high-density fibre glass wool foam insulation. The sound reduction index is increases for the panel with cavity insulation than for the other two systems. The sound reduction index of the cavity panel with insulating material is greater than that is without insulation by about 10dB compared to the non-insulated panel. It is seen that the dips occur at 125Hz in the low frequency region, because of the presence of cavity insulation, the dips are more predominant in the low frequency region, whereas it is not so in the other two cases.
Table 5.3 Comparison of Sound reduction index of lightweight materials

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Materials</th>
<th>ODEON values (dB)</th>
<th>Experimental values (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coconut shell Hollow Blocks</td>
<td>63: 35</td>
<td>125: 30</td>
</tr>
<tr>
<td></td>
<td>Coconut fibre Ferrocement Panel with cavity</td>
<td>63: 25</td>
<td>125: 28</td>
</tr>
<tr>
<td></td>
<td>Coconut fibre impregnated panel with cavity insulation of fibre glass wool 50mm thick (48kg/m³)</td>
<td>63: 27</td>
<td>125: 27</td>
</tr>
</tbody>
</table>
Figure 5.8 Comparison of Odeon (-----) and measured (——) Sound reduction index of Coconut shell Hollow Blocks.
Figure 5.9 Comparison of Odeon (------) and measured (-----)
Sound reduction index of Coconut fibre ferrocement Panel.
Figure 5.10 Comparison of Odeon (-----) and measured (———)
Sound reduction index of Coconut fibre ferrocement Panel with cavity.
Figure 5.11 Comparison of Odeon (------) and measured (——) Sound reduction index of Coconut fibre impregnated panel with cavity insulation of fibre glass wool 50mm thick (48kg/m³).
5.5 SUMMARY

This chapter gives the details of the theoretical predictions using ODEON package for low frequency regions (63-4000Hz). Transmission loss of the materials like ferrocement panel, Hollow blocks are assessed for their performance of sound transmission in the low and mid frequency regions.

Modeling was done by coupling both the rooms of the TL suite with the test sample opening and the analysis was done. It was observed that the ferrocement panels, foam concrete and hollow blocks perform well in the low frequency region. The transmission losses of the hollow blocks were higher when compared to the other two materials.

Transmission loss of the material studied were then compared with the experimental values and there is a variation of sound transmission performance of 5-10dB between the values. The reasons could be due to strong modal frequencies present and other deviation from the physical properties associated with the panel.
Figure 5.12 Sound pressure distributions at source and receiver rooms at 63Hz on 120mm thick
Figure 5.13 Sound pressure distribution at source and receiver rooms at 125Hz on 120mm thick
Figure 5.14 Sound pressure distribution at source and receiver rooms at 250Hz on 120mm thick
Figure 5.15 Sound pressure distribution at source and receiver rooms at 500Hz on 120mm thick
Figure 5.16 Sound pressure distribution at source and receiver rooms at 1000Hz on 120mm thick
Figure 5.17 Sound pressure distribution at source and receiver rooms at 2000Hz on 120mm thick
Figure 5.18 Sound pressure distribution at source and receiver rooms at 4000Hz on 120mm thick
Figure 5.19 Sound pressure distribution at source and receiver rooms at 63Hz on 170mm thick...
Figure 5.20 Sound pressure distribution at source and receiver rooms at 125Hz on 170mm thick
Figure 5.21 Sound pressure distribution at source and receiver rooms at 250Hz on 170mm thick
Figure 5.22 Sound pressure distribution at source and receiver rooms at 500Hz on 170mm thick
Figure 5.23 Sound pressure distribution at source and receiver rooms at 1000Hz on 170mm thick
Figure 5.24 Sound pressure distribution at source and receiver rooms at 2000Hz on 170mm thick
Figure 5.25 Sound pressure distribution at source and receiver rooms at 4000Hz on 170mm thick
Figure 5.26 Sound pressure distribution at source and receiver rooms at 63Hz on 220mm thick
Figure 5.27 Sound pressure distribution at source and receiver rooms at 125Hz on 220mm thick
Figure 5.28 Sound pressure distribution at source and receiver rooms at 250Hz on 220mm thick
Figure 5.29 Sound pressure distribution at source and receiver rooms at 500Hz on 220mm thick
Figure 5.30 Sound pressure distribution at source and receiver rooms at 1000Hz on 220mm thick
Figure 5.31 Sound pressure distribution at source and receiver rooms at 2000Hz on 220mm thick
Figure 5.32 Sound pressure distribution at source and receiver rooms at 4000Hz on 220mm thick
Figure 5.33 Sound pressure distribution at source and receiver rooms at 63 Hz on coconut fl
Figure 5.34 Sound pressure distribution at source and receiver rooms at 125 Hz on coconut fl
Figure 5.35 Sound pressure distribution at source and receiver rooms at 250 Hz on coconut f
Figure 5.36 Sound pressure distribution at source and receiver rooms at 500 Hz on coconut 1
Figure 5.37 Sound pressure distribution at source and receiver rooms at 1000 Hz on coconut
Figure 5.38 Sound pressure distribution at source and receiver rooms at 2000 Hz on coconut
Figure 5.39 Sound pressure distribution at source and receiver rooms at 4000 Hz on coconut