Course: MSc in Environmental and Architectural Acoustics
Unit: Measurement and Behaviour of Sound
Subject: Measurement of Absorption coefficient in the Reverberation Chamber.

Aim

- To measure the absorption coefficient in the reverberation chamber.
- To obtain experience of reverberation time measurements
- To obtain practical experience of error calculations

Instrumentation

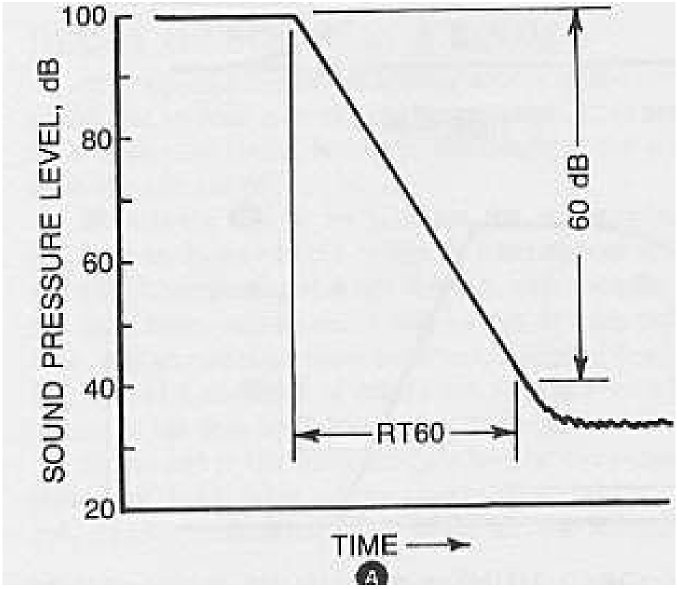
1. Loudspeaker with a power amplifier
2. Noronic 823 analyser. Incorporates a random noise generator, a microphone amplifier and a post processing module for RT calculations.
3. Microphone
4. Tripod
5. Calibrator

Introduction and Theory

A Reverberation Time

The reverberation time (RT) represents the persistence of sound in a closed space after a noise source cut-off. The reverberation time is defined as the time in seconds necessary for the sound pressure level to decrease by 60 dB after the sound is cut-off. It is a function of frequency.

The decay curve represents the time history (level vs time) at a specified frequency band (normally 1/3 or 1/1 octave band). The reverberation time is calculated from the decay curve (slope of straight line approximation)



B. Absorption coefficient of a porous sample placed in reverberation chamber

By measuring RT in a reverberation chamber with and without a porous sample one can measure absorption coefficient of this sample. In this experiment the porous material in question is situated behind steel doors in the reverberation chamber. Instead of moving it in and out of the reverberation chamber you can simply take measurements with the steel doors opened and closed.

Measurements must be taken in 1/3 octave bands. Each frequency is taken separately and an absorption coefficient and standard error calculated.
Average RT with absorber not exposed

$$T_{empty} = \frac{0.161V}{S\overline{\alpha}_0} \qquad \textit{Equation 1}$$

(All Ts are reverberation times, the more usual nomenclature is T_{60} but using this meant a mess of subscripts).

Average RT with absorber exposed, doors open

$$T_{sample} = \frac{0.161V}{(S - S_s)\overline{\alpha_0} + S_s\alpha_s} \qquad \textit{Equation 2}$$

Where V is the volume of the room
S is the surface area of the room
A_0 is the average absorption coefficient of the room
S_s is the sample's surface area
A_s is the sample's absorption coefficient

The absorption coefficient can be calculated from EQ 1 and EQ 2. You should derive the following equation.

$$\alpha_s = \frac{0.161V}{S_s}\left(\frac{1}{T_{sample}} - \frac{S - S_s}{ST_{empoty}}\right) \qquad \textit{Equation 3}$$

C. Calculation of Errors

To calculate the errors in the calculation of absorption coefficient, we must evaluate the errors in other parameters in EQ 1 and EQ 2. The main errors will come from the reverberation times. (why?)

The errors in reverberation times can be calculated from the standard deviation. If the average reverberation time is T and the individual times T_1, T_2,.. , T_n (n measurements)

$$\delta T = \frac{1.96\sigma_{n-1}}{\sqrt{n}} \qquad \textit{Equation 4}$$

Where σ_{n-1} is the best estimate of the standard deviation of the reverberation times; this can be found as a statistical function on most calculators and spreadsheets. δ T is a 95% confidence estimation of the standard error.

For example, if the measurements of reverberation time are: 0.5, 0.7,0.65,0.55,0.6,0.6 sec
T=0.6 sec, n=6, σ_{n-1} =0.0707 sec, δ T=0.05658 sec
So the reverberation time is given by : T=0.6 < 0.06 sec
So a 95% of the time, if we measure the room, the reverberation would lie between 0.54 and 0.66 sec

Once the errors in the reverberation times are estimated, the error in the absorption coefficient can be calculated using the following formulae:

$$\delta\alpha_s = \frac{0.161V}{S_s}\left(\frac{\delta T_{sample}}{T^2{}_{sample}} + \frac{(S - S_s)\delta T_{sample}}{ST^2_{empty}}\right) \qquad \textit{Equation 5}$$

Example

The reverberation time of the room without the absorber is 4 <0.5 sec
The reverberation time of the room with the absorber exposed is 2 <0.3 sec
Volume of the room 200m^3
Surface area of the room 300m^3
Surface area of absorption 12m^2
Absorption coefficient of sample=0.7<0.3 sec

So, if the measurement was repeated 95% of the time the absorption coefficient would lie between 0.4 and 1.0 sec

Question (Challenging one)

Estimate errors for the volume and surface area calculations. Include this in the calculations of the error of the absorption measurements, to get a true value.

Procedure

1. Connect the output of Norsonics to the power amplifier and from there to the loudspeaker.
2. Place the loudspeaker facing the corner. Select a number of microphone positions which are 1m from the room surface. 2m from the loudspeaker and all at different heights. Ideally, there should be more than one loudspeaker position, but you will probably only have a limited number of positions. The standard requires the use of the following number of positions:

100 to 250 Hz	12 positions	6microphones by 2 loudspeakers
315 to 900 Hz	*9 positions*	*3 microphones by 3 loudspeakers*
1000 to 5000 Hz	*6 positions*	*2 microphones by 3 loudspeakers*

   Our suggestion is 3 microphone positions by 2 loudspeaker positions.
3. Uise of Norsonic analyser
   i) Set Norsonic to REV time and 1/3 octave.
   ii) The Norsonic analyser has the ability to automatically scan a set of frequencies, store and average the stored values. Measure the reverberation time in the frequency range 100 Hz to 3150 Hz in 1.3 octave bands.

   Scanning
   - *a) To complete a frequency scan from 100 Hz to 3150 Hz, press "100 Hz" button and then press "scan". The instrument will continue to scan provided it accepts the result but will stop if the backgreoun noise is too high, or if there is an overload*
   - *b) To view the current values press "last". For the purpose of calculatin gerrors (Eq 5) you will have to write doewn (or print out) reverberation times for each microphone / loudspeaker position.*
   - *c) To store the current set of results press "store" and then "avrg T".*

   iii) Repeat ii) for two other microphone positions, then the same for the second loudspeaker position.
   iv) Print out the average reverberation time for all six measurements. Alternatively use your individual results to obtain the average for each frequency. You will need this data to substitute in Eq 3.
   v) Print out one sample decay curve for a low frequency and one for high frequency. Comment on the difference.
   vi) Clear the memory of the Normonic after you have obtained the results for the empty room. TO do that press "clear" and then "Avrg T".

vii) *Repeat ii) to vi) with the absorbent in the room by opening the doors.*

4. Now determine the absorption coefficient of the porous material as a function of frequency (use Eq 3)
5. Calculate confidence limits for α s (Eq 5) for each frequency.
6. Plot a graph of absorption coefficient against frequency with confidence limits.

Appendix 1. Effect of doors on absorption measurements

The formula assumes that the absorption of the steel door is either negligible or the same whether the doors are open or closed. To treat the case more strictly:

With the doors shut the total absorption (product of area and corresponding absorption coefficient) is:

$$A_{ds} = S_r \overline{\alpha}_r + S_{ds}\alpha_{da}$$

Where S_r is the room surface area, excluding the doors
α_r is the room surfaces absorption coefficient excluding the doors
S_{ds} is the door surface area (shut)
α_{ds} is the door absorption coefficient

With the doors open the total absorption is

$$A_{do} = \left(S_r - S_{bd}\right)\overline{\alpha}_r + S_{do}\alpha_{do} + S_s\alpha_s + S_{bd}\alpha_{bd}$$

Where S_s is the sample surface area
α_s is the sample absorption coefficient
S_{do} is the door surface area (open)
α_{do} is the door absorption coefficient (open)
S_{bd} is the surface area of the wall behind the open doors
α_{bd} is the absorption coefficient of the wall area behind the door

The formula given in the lab sheet can only be true if $\alpha_{bd} = \alpha_i$ and wither $A_{do} = A_{ds}$ and/or $A_{do} = A_{ds} = 0$.The problems are:

1. When open, the doors are exposed on two sides instead of one, so expected door absorption to increase $A_{do} > A_{ds}$
2. The absorption of the doors will mainly be modal vibration. These modes will be different with the doors open and closed because the doors are supported differently at the edges. Hence the absorption coefficient will change $\alpha_{do} <> \alpha_{ds}$
3. Ωιτη τηε δοορσ οπεν τηε δοορσ αρε παρτιαλλψ σηιελδινγ α σεχτιον οφ τηε ω αλλ ανδ τραππινγ α σμαλλ ϖολυμε οφ αιρ. Τηισ σπαχε βεηινδ τηε δοορ ισ νο λονγερ ιν τηε βοδψ οφ τηε ροομ ανδ ιτσ βεηαϖιουρ ωιλλ βε χομπλιχατεδ. Ιτ μιγητ βε εξπεχτεδ τηατ τηε εφφεχτιϖε ϖολυμε οφ τηε ροομ ωουλδ δεχρεασε (μ αψβε α μαλλ εφφεχτ) ανδ τηε ωαλλ αρεα βεηινδ τηε δοορσ ωιλλ νοτ χοντριβ υτε ιτσ φυλλ αβσορπτιον το τηε ροομ $\alpha_{bd} <> \alpha_r$.