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Sound transmission loss of expansion chambers with staggered upper and lower chamber

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ABSTRACT

The sound transmission losses across expansion chambers with the upper and lower chambers offset (staggered) inside a duct were studied experimentally in the present investigation. The sound transmission losses were measured using the four microphone method (one pair upstream and one pair downstream of the chambers). Pressure transducers were used to record the pressure fluctuations within the chambers. An anechoic termination was included in order to minimize the acoustic reflection at the exit of the test rig. Compared to the conventional expansion chamber, the staggered chamber setting results in a higher sound transmission loss at higher frequencies (below the first duct cut-off) and such increase in the sound transmission loss increases with the degree of chamber offset. Such rise in the sound transmission loss is abrupt showing that there exists a critical frequency at which the change is excited. The increase in the sound transmission loss is also relatively broadband, though it drops as the forcing frequency is further increased. The critical frequency appears weakly dependent on the degree of offset. On the low frequency side, the increase in the chamber offset does not result in significant change in the sound transmission loss, except that a larger fluctuation of the latter can be observed at increased offset.

INTRODUCTION

The noise generated by the air conditioning and ventilation systems in modernized high-rise commercial buildings has long been an important problem of building services engineers [1]. This noise propagates into the occupied zones of the buildings and affecting significantly the indoor environmental quality. There have been efforts in the past few decades on setting up indoor noise design criteria, for instance Beranek [2] and Kingsbury [3]. In addition, there have been researches into the methods for the attenuation of the noise before it reaches the occupied zones. Typical examples include the dissipative silencers [1], resonators [4], hybrid silencers [5], the expansion chambers and mufflers [6], and more recently the drumsilencer proposal from Huang and Choy [7]. The use of active control has also been studied (for instance, Canevet [8]).

The expansion chamber is simple and easy to install. Howver, its performance is restricted by its length and the area expansion ratio [6]. It also introduces static aerodynamic pressure loss because of the flow separation at its entry and exit. Lau and Tang [9] studied the performance of such chambers with tapered inlet and outlet. They explained their observations in term of the interactions between the various acoustic modes inside the tapered chambers. There are many complicated muffler design which make use of the modal interaction in controlling the sound transmission loss [10]. However, they are too complicated and are not so situable for duct use because of the anticipated high static aerodynamic losses and thus non-effective use of energy.

The simplest conventional expansion chamber consists of an upper and a lower cavity of equal volume. For low frequency application, the plane wave inside the ductwork will reach the singular points (upper and lower cavity edges) at the same time and thus the sound scattering takes place simultaneously there. It is believed that the phase of the scattering can affect the various interferences within the chambers and thus can have substantial effects on the overall sound transmission loss across the chamber. Also, the resonance inside the chamber can have serious effects on the sound transmission characteristics.

One simple way to create such a non-simultaneous scattering at the cavity edges and additional resonances is by staggering the upper and lower chamber. In the present study, an experiment was setup to examine the sound transmission loss across expansion chambers with staggered upper and lower chambers in the absence of air flow inside the chambers. The effect on the degree of offset/staggering on the sound transmission loss is studied in detail.

EXPERIMENTAL SETUP

The test duct and the expansion chambers in the present study were made of Perspex of thickness ~12mm in order to avoid wall vibration which can result in additional transmission loss due to breakout problem. The cross section of the main duct was 173mm (width) by 150mm (height). The upper and lower chambers have the same volume. The depth and length of each chamber were 70mm and 100mm respectively. An anechoic ending was used to minimize reflection from the end of the test duct, while a loudspeaker provided the acoustic forcing. Figure 1 shows the schematics of the experimenttal setup, the important dimensions and the nomenclatures adopted in the present study.

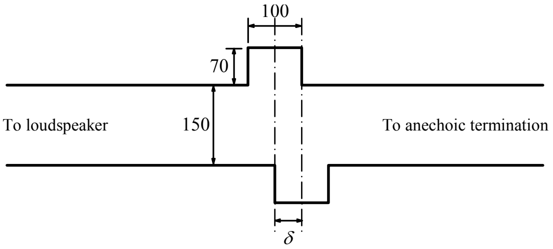

Figure 1. Setup schematics and nomenclatures adopted (all dimensions in mm)

The degree of the staggering or offset is represented by δ. Figure 2 illustrates the sound power reflection coefficient along the duct without the chamber but with the anechoic ending installed. The working frequency of the present study therefore starts from 200Hz up to the first cut-off duct frequency, which is 990Hz. Within this frequency range, the wave energy inide the duct is mainly carried by the planar acoustic modes at locations sufficiently away from the chambers. The reflected energy is less than 5%.

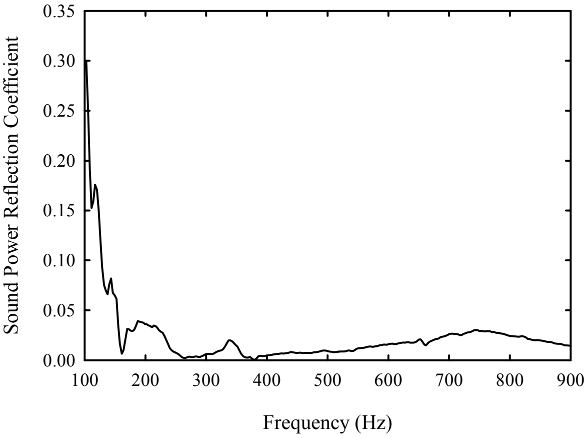

Figure 2. Anechoic ending performance

Four microphones (Brüel & Kjær Type 4935, ¼”) mounted flushed with the internal duct wall were used to measure the sound pressure fluctuations. The two microphone method of Chung and Blaser [11] was used to resolve the incident and reflected wave magnitudes in the duct section upstream of the chambers and the transmitted wave magnitude downstream of the chambers. The sound transmission loss, hereinafter denoted as *TL*, is defined as the ratio of the incident wave intensity to the transmitted wave intensity in dB. Details of the formulation of the method involving four microphone signals has been given in Tang and Li [12] and is not repeated here.

All the signals were recorded by using the DAT recorder SONY PC208Ax and the spectral analyses were carried out using MATLAB. Throughout the experiment, the sound pressure levels generated by the loudspeaker within the test rig were at least 50dB above the background noise over the frequency range concerned such that the latter had no effect on the measurement.

RESULTS AND DISCUSSIONS

The offset distance δ was varied from 0mm to 100mm in a regular interval of 10mm in the present experiment. Figure 3 illustrates some examples of the sound transmission loss across the chambers. It can be seen that the conventional symmetrical expansion chamber produces a *TL* which is in principle increases with frequency especially when the frequency increases beyond 600Hz, though some dome-like variation is seen. This is due to the generation of higher chamber modes at the entrance of the chamber which cannot propagate into the downstream duct [12]. The first cut-off of the transverse chamber mode is around 590Hz.

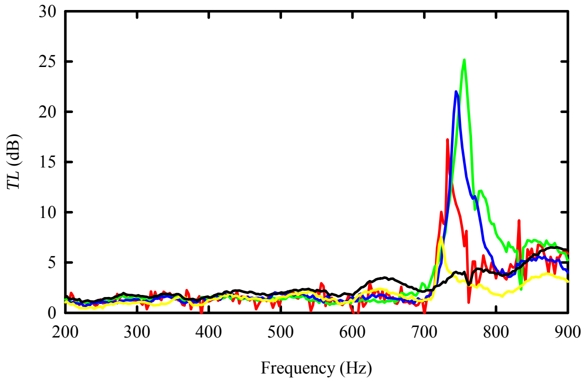

Figure 3. Sound transmission loss across chambers
— : δ=0mm; — : δ=20mm; — : δ=50mm;
— : δ=70mm; — : δ=100mm

Also notice from Figure 3 is that there is a prominent *TL* peak at frequency between 700Hz to 800Hz once the upper and lower chambers are staggered. Such peak *TL* appears to grow rapidly after reaching a particular frequency threshold and its decay is relatively gentle. The magnitude of the sound transmission loss and the frequency of the *TL* peak appear to increase with increasing offset distance δ. In addition, the frequency band of the active sound attenuation increases with δ as well.

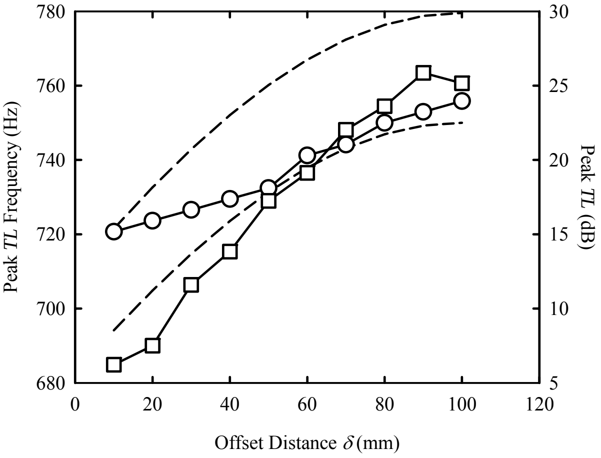

Figure 4. Effects of offset distance on *TL*
○ : Peak frequency; ☐ : peak *TL*;
– – – : Predicted resonance frequency range

It can be observed from Figure 4 that the increase in the peak *TL* frequency and the maximum *TL* magnitude with the offset distance are quite linear. The variation of *TL* with the offset distance seems to be flattening out when the latter reaches 100mm, where the upper and lower chambers are basically separated. One can also notice that the peak frequency increases very linearly with δ for $\delta < 50$mm, but a weak jump appears for 50mm < δ < 60mm.

The relatively abrupt rise in the *TL* shown in Figure 3 tends to imply that some sort of destructive interference is occurring once the upper and lower chambers are staggered as the wave scattered by the two leading edges of these chambers will arrive at a downstream location at different phases and/or some kind of resonance is taking place within the staggered chamber region which results in low sound pressure at the exit of the chamber assembly. The latter phenomenon is observed by Lau and Tang [9] and more recently in Tang and Lam [13].

The edge scattering is not straight-forward in the analysis and thus is left to further study. However once the upper and lower chambers are staggered, there exists two possible resonances within the staggered cavities. One is between the leading edge of the lower chamber to the upper right hand corner of the upper chamber. The other two are between the leading edge of the lower chamber and the edges of the upper chamber. However, the latters are at frequencies higher than the frequency range of the present study, where the possibility of higher mode propagation is very high and the two microphone method will then not be useful.

For the possible resonance between the lower leading edge and the corner, the wavelength λ (in mm) is approximately

$$\lambda = 2\sqrt{(100-\delta)^2 + 220^2}\ , \tag{1}$$

and the resonance frequency so predicted, f_{res}, is

$$f_{res} = \frac{c}{\lambda} = \frac{c}{2\sqrt{(100-\delta)^2 + 220^2}}\ , \tag{2}$$

where c is the ambient speed of sound. For c varies from 330m/s to 343m/s, the range of f_{res} for the present offset distance, which is shown in Figure 4, appears to cover the measured peak *TL* frequencies in the present study. For $\delta \geq$ 50mm, the predictions are reasonably close to the measured ones. The exact reasons for the mismatch are not definitely known and are left to further investigation. However, one can notice from Figure 3 the conventional chamber (δ = 0mm) is weak in the *TL* at a frequency close to 700Hz. This indicates that there is a chamber resonance which tends to enhance sound propagation occurring around such frequency. For small δ, such effect may still be prevailing such that the effect of the abovementioned additional resonance may have been masked.

Previous experiences of Lau and Tang [9] and Tang and Lam [13] suggest that the occurrence of resonance can enhance or reduce sound transmission. Expecting high pressure at the leading lower chamber edge and the upper right hand corner of the upper chamber during the resonance, a low pressure region will be created at approximately midway between these two points. The lower *TL* at the first cut-off of the transverse chamber mode suggests that this mode tends to produce a high pressure region at the exit if the chamber. As frequency increases away from that cut-off frequency, the contribution from this mode becomes weaker and weaker, and thus the peak *TL* magnitude increases with increasing offset distance. The abovementioned transverse mode does not exist for δ = 100mm.

It is also observed from Figure 3 that the staggering of the upper and lower chambers is not affecting much the *TL* at very low frequencies. However, the staggered arrangement tends to lower down the *TL* before the occurrence of the sharp resonance peaks.

CONCLUSIONS

An experiment was setup in the present study to investigate the effects of staggering the upper and lower cavities of an expansion chamber on the overall sound transmission characteristics across the chamber. The four microphone method was used to estimate the sound transmission loss.

Results show that the staggering of the two cavities gives rise to a sharp sound transmission loss peak, whose magnitude increases with the degree of staggering, which is represented by the offset distance in the present study. The frequency of this peak sound transmission loss also increases with increasing offset distance.

A simple analysis shows that the peak is very likely to be associated with an additional resonance between the leading edge of the lower cavity and the upper corner of the upper cavity. Further investigations are required.

ACKNOWLEGMENTS

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