The Effect of Frequency change on Transmission Losses in Low Frequency Resonator Tubes

Low Zhi Weng and Yousif Abdalla Abakr*

Department of Mechanical, Materials and Manufacturing Engineering, The University of Nottingham Malaysia Campus, Jalan Broga 43500 Semenyih, Selangor Darul Ehsan, Malaysia
*youfis.abakr@nottingham.edu.my

Abstract — Many thermoacoustic engines are designed to operate at atmospheric pressure with a relatively low frequency, therefore there was always a concern about the losses encountered through the bends in the loop of the engine. This paper investigates the transmission loss when travelling waves propagate through straight tubes or curved bends of different radii. This work is mainly focusing on travelling waves propagating in the loop with low frequency range and low pressure amplitude (25 – 95Hz and 7.1 Pa). The four-microphone method has been used to determine the sound pressure wave that propagates in the tube then the decomposition theory is used to calculate the transmission loss through the curved bends or the straight tube. From the results of this work, it is found that, all the curved bends and the straight tube have a maximum transmission loss at a frequency value between 30Hz to 35Hz for all cases. After the frequency of 35Hz, a constant rate of decrease of the transmission loss was observed for all frequencies larger than 35 Hz.

1. Introduction

This paper investigates the transmission loss of the travelling wave when it propagates through a straight tube or curved bend tube. This research mainly focuses on the low frequency range of sound with low sound pressure amplitude which is a typical situation in low pressure thermoacoustics engine operating at atmospheric conditions. Transmission loss is a natural acoustic phenomenon; it is the loss of sound intensity as the sound waves passes through a medium. These losses are due to the attenuation and spreading of the sound waves. It is important to know sufficient information about the transmission loss for each different radius of curved bends for a proper design of the thermoacoustic engine; although this knowledge has been widely used in ducting systems, mufflers and thermoacoustic engines, but the concentration of most of the previous studies focus on high frequency ranges. A typical thermoacoustic engine consists of many curved bends, resulting in significant losses of sound pressure in these curved bends, therefore it is required to minimize the losses to improve the efficiency of the engine.

2. Objectives

The main objective of this work is to investigate the acoustics losses when a travelling wave passes through a curved bend at low frequency range and low pressure amplitude. This investigation covers two cases of transmission loss; one of a curved tube and one of a straight tube, both are of the same total length. The transmission loss for each case is calculated by using the decomposition theory [1], [2]. The decomposition theory has been described by Sybert and used to measure the acoustic properties of materials such as impedance and the intensity of the incident and reflected components.

The four-microphone method has been used by Yunseon [3] to determine the transmission loss coefficient of the exhaust system but he has used the full transfer function. This full transfer function is an alternative method for the decomposition theory but both methods can be used to calculate the transmission loss. The transmission losses of materials that have been measured by Yunseon are operated under a high frequency range of sound and high sound pressure amplitude.

3. Methodology

The apparatus is separated into two parts; upstream and downstream. The upstream part is where the sound wave coming from driving speaker before it enters the bend; the downstream is the part after the bend. Two microphones are positioned at each one of the upstream and downstream parts. Each two microphones are positioned 30 cm apart. The four microphones and amplifier are connected to the PXI system. This PXI system is used to record and analyse the signal measured by each one of the four microphones. Besides, it is also used to send the signal to the speakers to generate a travelling wave at a specific frequency. The amplitude of the travelling wave is controlled by the amplifier. In this experiment there are two speakers, one is the driving speaker and the other one is the attenuation speaker. The attenuation speaker is used to attenuate the reflected component, β2 at the downstream so that the transmission loss in the curved bends and straight tube can be calculated. Both of these speakers are generating sound waves with the same frequency but of a different phase angle which is controlled by the PXI system. The dimensions of each of the curved tube and the straight tube are shown in Table 1. The details of the whole system are shown schematically in Figure 1.

Table 1: Detail of each curved bend and the straight tube

<table>
<thead>
<tr>
<th></th>
<th>Length (m)</th>
<th>Radius of Curvature (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curved Bend</td>
<td>0.550</td>
<td>0.115</td>
</tr>
<tr>
<td>Straight Tube</td>
<td>0.550</td>
<td>-</td>
</tr>
</tbody>
</table>

4. Results and Discussion

The results of transmission loss for the curved bend and straight tube is shown in figures 2, 3 and 4. These transmission loss values are calculated by using the decomposition theory and two-port s-parameters theory [4]. In figure 2, the transmission loss is plotted against the frequency in order to show the transmission loss values for each case at different frequencies. Based on the trend lines shown figure 2, the transmission loss curve for the curved tube and the straight tube were observed to have a peak at a frequency ranging between 30Hz to 35Hz at the constant amplitude of 7.1Pa for the incident component at the upstream. The maximum transmission loss was observed ranging between 0.83 dB for the curved tube to a value for 0.53 dB for the straight tube. The transmission loss is generally decreasing at a constant rate of 0.01dB/Hz in the range between 35Hz to 95Hz. That means the transmission loss values are
dependent on the frequency value since the amplitude of the incident
component at the upstream was fixed at a constant value for all
frequencies, this may be due to the dependence of the thickness of
the acoustic boundary layer on the frequency, resulting in lower
viscous losses as the frequency increases.
The straight tube has the lowest transmission loss compared to the
curved tube as shown in Figure 2. This is partially due to the
reflection at the bend of the curved tube as well as loss of momentum
loss due to direction change in the curved tubes. When the travelling
wave passes the curved surface, part of the wave will be reflected and
the rest will pass through the bend. So, this has caused the incident
component of the wave at the downstream to be lower than the
incident component at the upstream. Therefore, bends have higher
transmission loss compared with straight tubes.

The transmission loss can be represented in a non-dimensional
form by dividing the loss at each frequency by the straight tube loss
at the same frequency. A plot of the non-dimensional loss against
frequency is shown in Figure 3, the non-dimensional loss of the
curved tube was consistency has a higher value of about 1.6 up to a
frequency of about 70Hz, after which the non-dimensional loss starts
to increase linearly. This is believed to be due to the dominant
viscous loss at the lower frequency, while the influence of turbulence
and reflection starts to be stronger after the 70 Hz limit.
The results of each bend and straight tube are plotted in the form
of percentage transmission loss against frequency as shown in Figure
4. It is observed that there is a peak of percentage transmission loss
within the range of 30Hz to 35Hz for both of the curved tube and the
straight tube. The maximum percentage transmission loss at this peak
ranges between 11.85% for the straight tube and 17.26% for the
curved tube. The percentage transmission loss in figure 4 is
generally decreasing at a constant rate of 0.21%/Hz between the
ranges of 35Hz to 95Hz.

5. CONCLUSIONS
In this work, the decomposition theory and four-microphone method
are used to investigate the transmission losses for a curved tube a
straight tube. The investigation is focused on low frequency range of
sound waves. There is a maximum of transmission loss within the
range of 30Hz to 35Hz for both of the curved bend and the straight
tube. The transmission loss was found to decrease at a constant rate
with the increasing frequency. The curved tube exhibited higher
losses compared to the straight tube; this is due to the reflected
component from the curved surface giving a constant loss increase
for all frequencies. Based on these results it is recommended avoid
designing a thermoacoustic engine operating at the frequency range
of 30-35Hz, the recommended frequency will be between 90-100 Hz.

Acknowledgment
The authors would like to thank MOSTI Science fund for providing
the financial support for this research work. The authors would also
like to thank the SCORE project, UK, for providing technical support
for this research work.

References
acoustic properties using a two-microphone random-excitation
Measurement of the Exhaust system using 4-microphones with
impedance tube,” AVISS korea.
by Using Impedence Tubes,” Journal of the Korean Physical Society,
pp. 596-600, August 2008.