Chapter 6

Experimental Measurement of Transmission Loss

As seen in the previous chapter the accuracy of optimization technique depends upon many factors. There is need to validate the results with experimentation procedure to get 100% confidence level. This chapter is all about experimental set-up, experimentation procedure and measurement.

The most common approach for measuring the transmission loss of a muffler is to determine the incident power by decomposition theory and the transmitted power by the plane wave approximation by using anechoic termination. But it is difficult to get fully anechoic termination [12]. Thus another approach of two load method is used [110]. The measured transmission loss values are compared with those obtained by the FEM method demonstrating that transmission loss can be determined reliably with the experimental set-up developed. The two load method is easier to employ for measuring transmission loss.

6.1 Two Load Method

In the two load method, two loads should be different to keep results stable. Generally, two loads can be two different length tubes, a single tube with and without absorbing materials [110]. In the present work two loads were achieved by outlet tube with and without absorbing material as shown in Figure 6.1.

The two load method is based on the transfer matrix approach. Using the transfer
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Figure 6.1: Two configurations and schematic model of a muffler

Configuration A

Configuration B

Figure 6.1: Two configurations and schematic model of a muffler
matrix method, one can readily obtain transmission loss of any muffler by obtaining four pole parameters from the four positions of microphones as shown in Figure 6.1.

6.2 Experimental Set-up

A schematic diagram of experimental set-up for calculating TL of simple expansion muffler is shown in Figure 6.2. It consists of a noise generation system, noise propagation system and noise measurement system. The TL is measured by transfer function method. The set-up has the following main components.

- Impedance tube
- Data acquisition system
- Noise source with amplifier
- Sound pressure measuring microphones

Impedance tube is a rigid tube through which sound propagates and reflects from test sample which results in creation of standing waves in it. It has measuring locations at specific distances from test sample where the acoustic pressure is measured. A sound source device is connected at one end of impedance tube and test muffler at the other end. As we are interested in incident and transmitted wave, two impedance tubes are used on either side of the muffler. The main purpose served by impedance tube is providing guidance to sound wave as required for plane wave propagation.

The data acquisition system used is a four channel FFT analyzer (OROS OR34, 4 Channel) with an interface for the control and setting of analyzer. A fourier transformer converts time signal data into frequency signal data and vice versa; an FFT rapidly computes such transformations. As a result, FFT is widely used for many applications in engineering and science.

Figure 6.3 shows OROS, 4 channel, compact, real time multi analyser along with required instruments and accessories. OR34 is the synthesis of the ultimate 3 series technology, that integrates the best of noise and vibration analysis technology in an ultra mobile instrument. It is low weight, portable and robust instrument which can be used with laptop for intensive use.
Figure 6.2: Schematic diagram of experimental set-up with its components
Figure 6.3: FFT analyzer and accessories
Main features of FFT are as follows.

- Ultra-light: 1.4 kg
- Real-time bandwidth 40 kHz
- ± 10 V Inputs, 24 bits, ICP
- 100 Mbits/Ethernet
- AC/DC power supply
- 2 external triggers/tachometers inputs
- 1 generator output

FFT collects the pressure data from microphones (PCB 377C10 pressure field) and feeds it to data recording storage system via BNC cable. FFT also has a single output channel which is fed to speaker through analyzer. A random noise signal is generated in the same analyzer and directed to the speaker (Ahuja-AU60) via amplifier (Ahuja SSB-45EM). The reason behind using random noise (white noise) is that it contains equal power density of noise for each frequency.

Sound source used is of high power to produce at least 110 dB of noise. Pressure field microphones are used for measurement. The two microphones are sufficient as transfer function method is used. Transfer function is evaluated for each set of readings.

### 6.3 Experimental Procedure

Experimentation for pressure measurement mainly consists of analyzer setting and data processing for TL calculation. The experiment is performed for frequency range of 50 to 3400 Hz. The measurements are taken in two slots with two locations 1-1’ and 4-4’ (refer Figure 6.2) respectively to cover desired frequency range [111]. The locations 1-2-3-4 are used for measuring pressure in frequency range 50-400 Hz, while the locations 1’-2-3-4’ are used for measuring pressure in frequency range of 400-3400 Hz. The first set of readings is taken for no load condition with both frequency ranges and same procedure is repeated for with load condition. Two microphones are used for measurement, which are sufficient for measurement of transfer function between sound pressures measured at two
locations. One microphone is placed at location 3 and other placed at location 1, 2 and 4 respectively to get transfer function $H_{31}$, $H_{32}$ and $H_{34}$ with respective locations. All other locations except locations where microphones are inserted are sealed with plugs to avoid sound leakage. The sound leakage is tested and wax is used to seal these leaks. The obtained transfer functions are then directly used in four-pole element calculations to get TL.

A random noise signal is generated with frequency range 10 to 5 kHz. The speaker noise spectrum is kept 10 to 15 dB higher than the background noise for all frequencies of interest. The loudspeaker is operated for 5 to 10 minutes so that the temperature inside the tube is stabilized. The sound leakage is tested and wax is used to seal these leaks. The precaution is taken while changing the microphone to other location. Correction to transfer function is added for considering the microphone mismatch.

$$H_c = \sqrt{H_{ij} \times H_{ji}}$$  \hspace{1cm} (6.1)

$$H_{ij\text{(corrected)}} = \frac{H_{ij\text{(measured)}}}{H_c}$$  \hspace{1cm} (6.2)

This data is then post processed with the help of NVGate 7.0 in FFT module to get frequency domain data. From frequency data transmission loss is calculated.
6.4 Post Processing

By using two microphones (random excitation) data is collected from FFT. From the data, transfer functions are calculated from the four positions of the microphones and processed with the following calculations. Substituting these transfer functions in four pole parameters transmission loss is calculated.

Neglecting flow of air, the four pole parameters for elements 1 – 2 can be expressed as

\[
\begin{pmatrix}
A_{12} & B_{12} \\
C_{12} & D_{12}
\end{pmatrix} = \begin{pmatrix} \cos(kl_{12}) & i\rho c \sin(kl_{12}) \\ i\rho c \sin(kl_{12}) & \cos(kl_{12}) \end{pmatrix}
\]  

(6.3)

The four pole parameters for elements 2 – 3 can be expressed as

\[
\begin{pmatrix}
A_{23} & B_{23} \\
C_{23} & D_{23}
\end{pmatrix}
\]

(6.4)

where

\[
A_{23} = \frac{\Delta_{34}(H_{32a}H_{34b} - H_{32b}H_{34a}) + D_{34}(H_{32b} - H_{32a})}{\Delta(H_{34b} - H_{34a})}
\]

(6.5)

\[
B_{23} = \frac{B_{34}(H_{32a} - H_{32b})}{\Delta_{34}(H_{34b} - H_{34a})}
\]

(6.6)

\[
C_{23} = \frac{(H_{31a} - A_{12}H_{32a})(\Delta_{34}H_{34b} - D_{34}) - (H_{31b} - A_{12}H_{32b})(\Delta_{34}H_{34a})}{B_{12}\Delta_{34}(H_{34b} - H_{34a})}
\]

(6.7)

\[
D_{23} = \frac{B_{34}(H_{31a} - H_{31b}) - A_{12}(H_{32b} - H_{32a})}{B_{12}\Delta_{34}(H_{34b} - H_{34a})}
\]

(6.8)

The term \(H_{ij}\) represents transfer function between \(P_i\) and \(P_j\) \((H_{ij}) = (P_j/P_i)\). The four pole parameters for elements 3 – 4 can be expressed as

\[
\begin{pmatrix}
A_{34} & B_{34} \\
C_{34} & D_{34}
\end{pmatrix} = \begin{pmatrix} \cos(kl_{34}) & i\rho c \sin(kl_{34}) \\ i\rho c \sin(kl_{34}) & \cos(kl_{34}) \end{pmatrix}
\]  

(6.9)
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By cascading these matrices final transfer matrix is

$$\begin{pmatrix} A_{14} & B_{14} \\ C_{14} & D_{14} \end{pmatrix} = \begin{pmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{pmatrix} \begin{pmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{pmatrix} \begin{pmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{pmatrix}$$  \hspace{1cm} (6.10)

$$TL = 20 \log_{10} \left[ \frac{1}{2} \left( \left| A_{14} + \frac{B_{14}}{\rho c} + \rho c C_{14} + D_{14} \right| \right) \right]$$  \hspace{1cm} (6.11)

The actual test set-up with required components is shown in Figure 6.4 and 6.5. Two configurations of set-up are used with respect to boundary conditions.
Figure 6.4: Actual setup without load
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Figure 6.5: Actual set-up with load
6.5 Validation of Experimental Set-up

After preparing the set-up for the experimentation it is necessary that results of known model are verified by the set-up to confirm the validity of experimental set-up.

Each reading is taken for time domain pressure signal with a recorder module of analyzer which runs for a period of 100 sec. Figure 6.6 shows sample time domain signal collected by data acquisition system from two microphones.

![Figure 6.6: Time domain signal collected by data acquisition system](image)

Inset of Figure 6.7 and Figure 6.8 show muffler geometry of central inlet, central outlet muffler and central inlet, side outlet muffler. Figures also show comparison of results of experiment with FEM (COMSOL) for these models. For both these models the experimental results show good agreement with the numerical results.

From the results it can be concluded that from the developed experimental set-up it is possible to measure the transmission loss of any muffler. The minor deviation of the experimental results from the numerical results may be due to leakage of sound from the surrounding or numerical error in computation.

The next chapter deals with results obtained in a variety of muffler configurations leading to determination of an optimal design of a silencer using grid search method,
Taguchi and ANOVA.

Figure 6.7: Comparison of results of experiment with FEM (COMSOL) for central inlet central outlet muffler

Figure 6.8: Comparison of results of experiment with FEM (COMSOL) for central inlet side outlet muffler