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Validation of set up for experimental analysis of reactive muffler for the determination of transmission loss: Part I

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Abstract

The internal combustion engine is the major source responsible for noise pollution. In an engine, the exhaust noise and the noise produced due to friction of various parts of the engine share maximum contribution to noise pollution. A muffler is a device used to reduce noise within the exhaust system. It is arranged along the exhaust pipe for the purpose of noise attenuation. In this article, the set up for experimental analysis is developed to predict the acoustic performance of reactive muffler using the two-load method, and it is validated by measuring transmission loss of known reactive muffler model by using finite element method. For the model, transmission loss obtained from experimental analysis was compared with that obtained from the finite element method. From the result, it can be concluded that the setup developed for experimental analysis is reliable to determine transmission loss of exhaust muffler, for low to mid frequency range.

Keywords

Transmission loss; reactive muffler; finite element method; two-load method

Introduction

In automotive exhaust system design, accurate prediction of sound radiation characteristics of reactive muffler carries significant importance. The acoustic analysis of exhaust muffler is characterized by numerous parameters such as insertion loss (IL) and transmission loss (TL). As per Gupta and Tiwari,[1] the frequently used parameter to evaluate the sound radiation characteristics of a muffler is TL. TL is defined as the difference between power incident on a muffler proper and the power transmitted downstream into anechoic termination. Gupta and Tiwari[2] state that the TL is independent of source, and it presumes anechoic termination at the tail pipe. The TL of an exhaust muffler can be predicted by analytical, numerical, and experimental method. The algebra associated with the analytical method is complicated; therefore, many times, it is difficult to analyze the acoustic performance using the analytical method. The numerical methods are useful for analysis of all types of muffler, but the results obtained from it may not be correct because of modeling errors, meshing errors, assumptions made while solving the partial differential equations, specifications of approximate boundary conditions, insufficient constraints, selection of meshing elements, types of meshing, and so on. Although the numerical methods carry these drawbacks, they can be used to analyze the models of complicated shapes. Therefore, the general practice is to optimize the model using the numerical method, and the results obtained are validated by experimental method. For the validation of set up for experimental analysis, it is important to test the results of model, for which numerical analysis is already carried out. The TL measured with experimental setup is compared with numerical method to demonstrate that the TL can be predicted reliably with the setup which is prepared. Gerges et al.[3] state that in general, the experimental results are used to verify the results obtained from analytical and numerical methods and also for the evaluation of overall performance of the model, to check whether the model satisfies the design requirements. In this research article, the two-load method is used for the prediction of TL.

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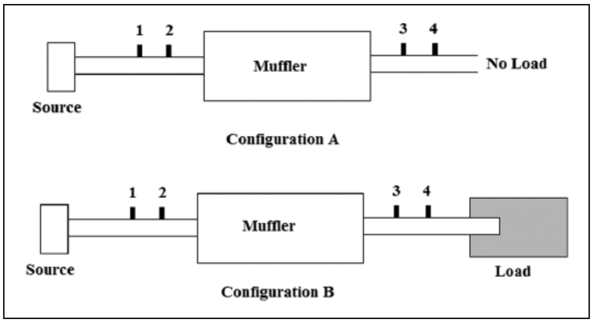

Figure 1. Double expansion chamber reactive muffler.

Theory of two-load method

Tao and Seybert[4] used the two-load method for experimental analysis of the muffler. The two-load method is based on the transfer matrix approach. Using the transfer matrix method, one can readily obtain TL of any muffler by using four-pole equations from four positions of the microphones. In this method, the two loads should be different to keep results stable. In this research, the two loads are achieved by using the outlet tube with and without absorbing material as shown in Figure 1.

Using the transfer matrix approach, one can find the TL of a muffler by using the four-pole equations from four positions of the microphones. Neglecting flow of air, the four poles for elements 1 and 2 can be expressed as

$$\begin{bmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{bmatrix} = \begin{bmatrix} coskl_{12} & j\rho csinkl_{12} \\ \dfrac{jsinkl_{12}}{\rho c} & coskl_{12} \end{bmatrix} \tag{1}$$

The four poles for elements 2 and 3 can be expressed as

$$\begin{bmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{bmatrix} \tag{2}$$

Where

$$A_{23} = \frac{\Delta_{34}\left(H_{32a}H_{32b} - H_{32b}H_{34a}\right) + D_{34}\left(H_{32b} - H_{32a}\right)}{\Delta_{34}\left(H_{34b} - H_{34a}\right)}$$

$$B_{23} = \frac{B_{34}\left(H_{32a} - H_{32b}\right)}{\Delta_{34}\left(H_{34b} - H_{34a}\right)}$$

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

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

The four poles for elements 3 and 4 can be expressed as

$$\begin{bmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{bmatrix} = \begin{bmatrix} coskl_{34} & j\rho csinkl_{34} \\ \dfrac{jsinkl_{34}}{\rho c} & coskl_{34} \end{bmatrix} \tag{3}$$

The term H_{ij} represents transfer function between P_i and P_j, where

$$H_{ij} = \frac{P_j}{P_i}$$

By cascading these matrices, the final transfer matrix is as follows

$$\begin{pmatrix} A_{14} & B_{14} \\ C_{14} & D_{14} \end{pmatrix} = \begin{pmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{pmatrix}\begin{pmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{pmatrix}\begin{pmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{pmatrix} \tag{4}$$

The TL is calculated as

$$\text{TL}=20\log_{10}\left[\frac{1}{2}\left(\left|A_{14} + \frac{B_{14}}{\rho c} + \rho c C_{14} + D_{14}\right|\right)\right] \tag{5}$$

By using two microphones with random excitation technique, TL can be calculated experimentally using equation (5).

Set up for experimental analysis

The set up for calculation of TL is as shown in Figure 2.

The set up for experimental analysis is consists of (1) a system for noise generation, (2) a system for noise propagation, and (3) a system for noise measurement.

The main components of the setup are sound source, amplifier, fast Fourier transform (FFT) analyzer, and impedance tube. The microphone positions are shown in Figure 2 as 1, 2, 3, and 4. The impedance tube is the rigid tube having measurement locations at certain distance. This tube acts as mean for sound propagation. Sound source is connected to one end of the impedance tube and the test muffler is connected to other end. The two impedance tubes are connected at both sides of the muffler because we are interested in incident as well as transmitted waves. The FFT analyzer is used as a data acquisition system. This system collects the pressure data from microphones and feeds them to the data recording storage system. It is also having output channel, which is connected to the speaker through an analyzer. The signal generated in an analyzer is a random noise signal, which is directed to the speaker through the amplifier. The random noise signal (white noise signal) is used because it contains equal power density of noise for each frequency. A high-power sound source is used to generate around 120 dB of noise.

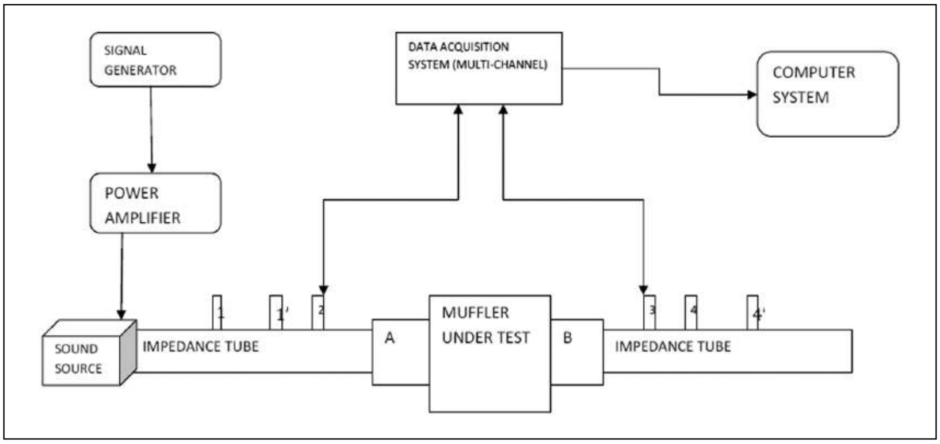

Figure 2. Set up for experimental analysis.

Figure 3. Actual experimental setup.

The two microphones are utilized because transfer function technique is used.

Procedure for experimental analysis

As per International Organization for Standardization (ISO 10534-2),[5] the procedure for experimental analysis consists of setting of analyzer and data processing for measuring the TL. The Figure 3 shows the actual experimental setup. The experiment is performed for frequency range 1–2000 Hz. The locations 1-2-3-4 are used for measuring the sound pressure in the frequency range 1–400 Hz, while locations 1'-2-3-4' are used for frequency range 400–2000 Hz.[5] One microphone is placed at location 3 and other placed at location 1, 2 and 4, respectively to get transfer function H31, H32, and H34 with respected locations. All the empty locations of microphones are sealed with a pin to avoid the sound leakage. The sound leakage test is carried out, and leakages are sealed using wax. The transfer functions which are obtained are used directly to four pole elements to calculate the TL.

Finite element method

In this research, the three-dimensional (3D) finite element method is used to calculate the TL of the muffler. The Mach number assumed is zero. The finite element analysis is carried out using COMSOL Multiphysics with no fluid structure interaction. Parametric solvers as well as linear solver are used as per COMSOL Multiphysics, User's Manual, COMSOL AB.[6] The frequency range considered for the analysis is 1–2000 Hz. The air density is taken as $1.2\ \mathrm{Kg.m^{-3}}$ and speed of sound is taken as $343\ \mathrm{m.s^{-1}}$, respectively. For meshing, automatic meshing and tetrahedral elements are used. The element size for the finite element domain is chosen to provide a minimum resolution of 12 elements per wavelength. Figure 4 shows the model for experimentation.

Results

The Figure 5 shows the TL curve obtained for the experimental analysis. The curve in green line shows TL obtained through numerical analysis, while the curve in red line shows the TL obtained through experimental analysis. From the graph, it can be observed that, the trough is occurring at a frequency of around 270 Hz and at 1300 Hz, while peaks are at 800 Hz and at around 1850 Hz. The peaks obtained shows the maximum TL, while troughs show the minimum TL. The frequency at which trough occurs, there is maximum sound pressure level inside the muffler, while the frequency at which peak occurs, the sound pressure level is minimum due to destructive interference. The region of relatively low attenuation can be observed in

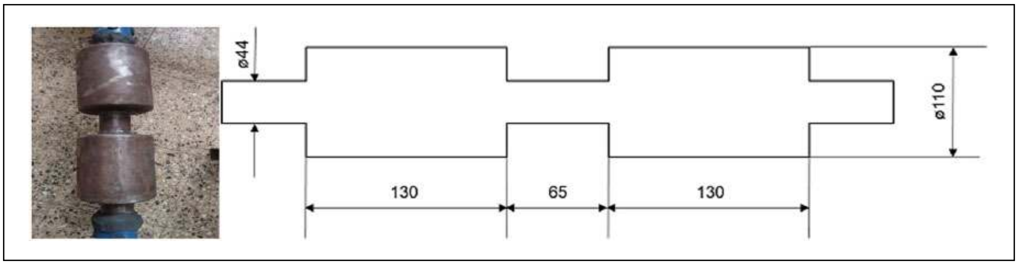

Figure 4. Model for experimentation.

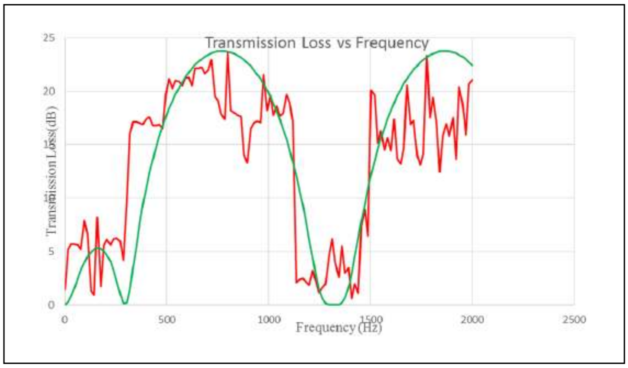

Figure 5. TL curve for experimental analysis.

the TL curve. The frequency at which the low-frequency pass region occurs decreases as the length of connecting tube increases. The TL at 800 Hz (design frequency) is 22.58 dB, while the TL calculated using numerical analysis is 23.70 dB. The percentage error calculated is 4.72% which shows that, the experimental results calculated are in good agreement with the numerical analysis.

Conclusion

In this research article, the results of the double expansion chamber reactive muffler are verified with experimental analysis using the two-load method. The results obtained through experimental analysis agreed well with numerical analysis. The small deviation in experimental result from that of numerical result may be attributed to leakage of sound from impedance tube to the surrounding, problems in generating white noise from FFT, or inaccurate surface finish quality of impedance tube. From the result, it is concluded that, the developed setup is suitable for measurement of TL of reactive muffler.

Declaration of conflicting interests

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