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Enhancing Sound Transmission Loss in Hybrid Mufflers with Change in Pipe Perforation and Using Absorptive Material

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Abstract: It is well known that baffled exhaust mufflers enhance sound transmission loss while lowering noise emissions. Sound transmission loss can be further reduced by adding sound-absorbing material inside the silencer. It has been demonstrated that carefully placed baffles in exhaust silencer systems improve acoustic performance by successfully lowering noise emissions. Sound waves are redirected and disrupted by baffles, which lessens the transmission of undesired noise and creates a more controlled and tranquil acoustic environment. The incorporation of sound-absorbing materials into mufflers is a significant development in noise control technology. Specialized materials are added to the muffler to improve sound wave absorption and drastically reduce noise emissions. This novel method not only enhances acoustic performance but also improves a variety of applications—from industrial gear to automobile exhaust systems—making them quieter and more enjoyable to use. A silencer was constructed for this research project using the finite volume method. The design's efficacy was demonstrated through experimental validation. The research project then used the finite volume technique to produce a silencer with the same dimensions. It then adjusted the design based on different flow percentages, adding a baffle and making pipe perforations, until the optimal silencer design was found. Additionally, this approach provides an optimal design and indicates which sound-absorbing material has the largest sound transmission loss.

Introduction

The ability of a vehicle's exhaust system to reduce noise and function generally acoustically is directly impacted by the amount of sound transmission loss in hybrid mufflers (Kashikar et al., 2021). Innovative methods that concentrate on changing muffler design and using cutting-edge sound-absorbing materials have been developed in the quest for quieter and more effective mufflers (Siano and D'Agostino, 2015). In addition to making driving more enjoyable, this quest for improved sound transmission loss is in line with stricter noise laws and the rising desire for eco-friendly, quieter cars (Wang et al., 2013).

It has been shown that the use of baffles in exhaust mufflers increases muffler transmission loss (TL) by more than 50%. Elsayed et al. (2017) used the Harmonic Boundary Element Method (BEM) with and without extensions on the baffles to investigate the effects of internal totally circular baffles with a single cantered hole on TL. The results showed that when baffles were used, the TL in the lower frequency spectrum reduced while it significantly improved in the mid-to high-frequency band (Elsayed et al., 2017). In a hybrid muffler, Horoub investigated the results of joining tapered expansion chambers of various sizes (Guhan et al., 2018). Computational fluid dynamics (CFD) tests on these connected expansion chambers revealed that extensions on baffles decreased the pressure drop within the silencer in comparison to a single expansion chamber of comparable size (Mohammad et al., 2020). The transfer matrix representation, which has been extensively utilised in the past to assess and quantify the acoustical characteristics of flow system components, serves as the foundation for the mathematical formulation

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(Muhammad et al., 2021). Although STL can be determined in some ways, the study in this paper uses the two-load approach. The four pole parameters are determined using rigid and anechoic termination, and the STL transfer matrix equation is derived (Olivieri et al., 2006). Mufflers are required to regulate the strong exhaust tones in automobile exhaust that range in frequency from 30 Hz to 1000 Hz and above (Philipson and Lawless, 2020).

There are two primary types of noise that an internal combustion engine produces when it flows through an exhaust system: low-frequency noise (below 800–1000 Hz), sometimes known as "breathing noise," and high-frequency noise (above 800–1000 Hz), sometimes known as “flow noise” (Emoto et al., 2023). Absorptive, reactive, and combination mufflers are the three types of mufflers (Torregrosa et al., 2018). The objective behind absorbtive mufflers is to absorb the sound of exhaust gases. Rock wool or other absorbing materials are wrapped around a perforated exhaust tube, allowing the sound to be absorbed and converted into tiny amounts of heat.

It was believed that the absorbing substance was homogenous. But this assumption isn't always true in the real world of automobiles. Hence, heterogeneous acoustic properties for fibrous materials were taken into consideration. (Rajadurai et al., 2015).

In this research work, wave one D analysis has been used and a muffler has been designed, in which three baffles have been installed at the beginning, the inlet and outlet pipes have been perforated at different percentages, and the sound transmission loss has been measured. Has gone. After this, the optimum perforation was found by making holes of different diameters in the inlet and outlet pipes and it was seen that at which perforation the maximum sound transmission loss is being obtained. After this, the sound transmission loss was observed by installing a fourth baffle at different positions, and it was measured that after finding out at which position the fourth baffle is giving the highest sound transmission loss, the optimum muffler.

Sound Absorbing Materials

Many materials are commonly used for acoustic sound absorption because they may reduce noise and control reverberation (Salleh et al., 2022). The precise frequency range that needs to be addressed, personal taste, and the space's acoustic requirements all play a role in the material selection (Fu et al., 2021).

Glass Fiber: Often used in panels or as loose-fill, glass fibre absorbs a broad range of frequencies (Won and Choe, 2020).

Rockwool: is appropriate for various applications since it is fire-resistant and offers great sound absorption (Krebelj, 2013).

Panels of Foam: Foam panels are useful for absorbing mid-to high-frequency sounds since they are lightweight and adaptable (Bravo et al., 2017).

Muffler Modelling Method and Analysis

Structure and Dimensions

Figure 1(a) depicts the exhaust muffler structure employed in this study, and Table 1 lists the precise specifications. Simplified to (b), the structure drawing primarily consists of the cavity component (intake and exhaust anechoic cavity), intake pipe, exhaust pipe, partition, and anechoic hole (intake pipe hole, partition hole, and exhaust pipe hole)(Z. Zhang et al., 2023).

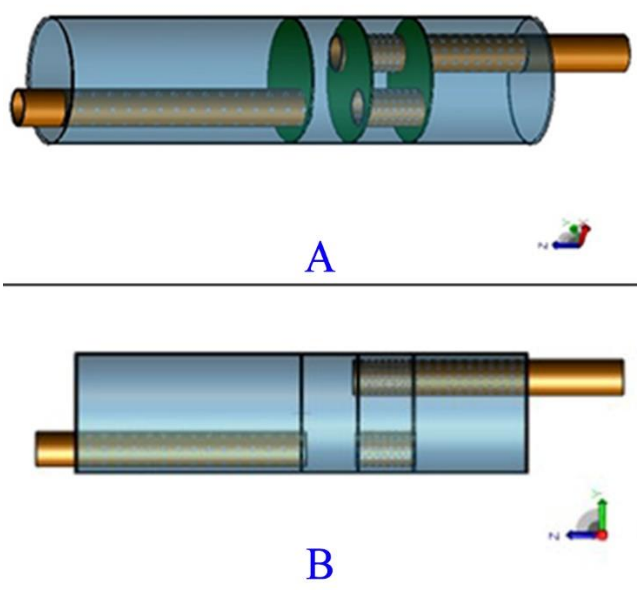

Figure 1. (A) Complex Muffler with baffle arrangement; (B) Simplified View of Complex Muffler with baffle arrangement.

Mesh Generation

Wave 1-D mesh development for muffler simulations includes several crucial processes. Make sure the 3D muffler shape is clean and gap-free before continuing. Provide material characteristics to the components based on the actual materials, make use of Wave's one-dimensional meshing tool, and select the appropriate element type (tetrahedral or hexahedral) based on the degree of complexity of the muffler (Zhang, 2020). To accurately capture details, refine the mesh in regions of interest, such as baffles or perforated tubes (Janssen, 1996). If a boundary layer mesh is necessary, think about adding one close to the muffler walls (Amor et al., 2022).

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Verify the mesh quality to ensure there is little distortion and the parts are well-shaped. (Eversman et al., 1975). Export the mesh in an acceptable format, such as STL. Import this mesh into Wave 1-D and connect it to the muffler geometry to configure the simulation's parameters, including flow characteristics and boundary conditions. Run the simulation to find out the gearbox loss and other details (Parrondo et al., 2006). Lastly, inferences are made from the simulation's results via post-processing wave analysis techniques.

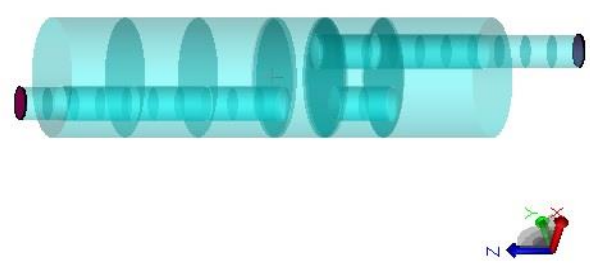

Figure 2. Mesh Generation of Complex Muffler with baffle arrangement

Simulation Model

Boundary Condition

Conditions at the inlet's edge

These conditions describe the properties of the fluid that normally enters the system at the intake manifold (Jena and Panigrahi, 2017). Various engine operating conditions can be achieved by varying mass flow rate, temperature, and pressure.

Conditions for Outlet Boundaries

Outlet boundary conditions at the exhaust end regulate how exhaust gases leave the system (Mir et al., 2023; Gaonkar et al., 2020). Before designing the experiments, it was crucial to define the problem's approach by specifying the number of boundaries, the number of iterations, and the type of outcome needed (Li et al., 2008). The paper's only strategy was to minimise noise, which it did by maximising transmission losses. Consequently, the "bigger the better" philosophy was used.

Conditions at Wall Boundaries

Characteristics of the MPPCP transmission response to arbitrary noise or turbulent disturbances that are specified over the spectrum (Bowden, 2017; Guo et al., 2023). A cross-spectral density function between the blocked pressures at two microphone positions statistically describes the wall-pressure fluctuations that are seen on the right side.

Simulation Analysis

In order to comprehend the functioning of an acoustic muffler, wave 1D research entails examining one-dimensional sound waves inside the muffler (Cardin et al., 2023). The muffler's design aims to reduce noise from exhaust gases (Li, 2023). To simulate the sound wave interactions in this experiment, researchers typically model the silencer as a duct with various cross-sectional areas and porous materials. The engine's first sound is the main or first wave (Münzel et al., 2014). In wave analysis, the muffler model was first designed in wave 3-D (Zhu and Ji, 2016). After this, the file is exported from Wave 3D and brought to Wave 1D. Here, the acoustic condition of the muffler is defined, such as placing the acoustic piston in the inlet and ambient in the outlet. Before doing modal analysis, the frequency range is also decided. In our study, the frequency range is from 50 to 3000 and then finally, the sound transmission loss is measured by doing muffler analysis (Aydın Sayılan et al., 2021).

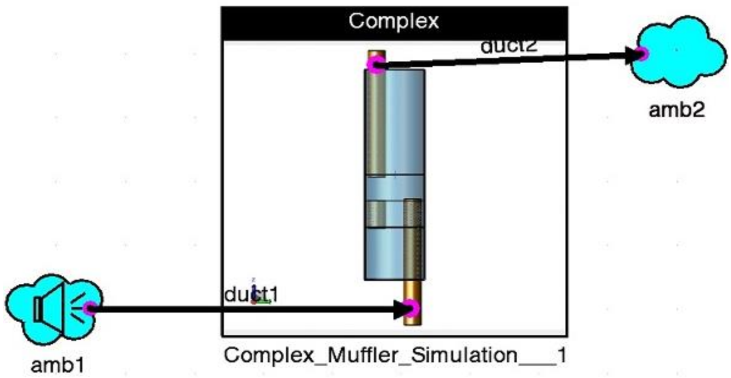

Figure 3. Simulation model for muffler analysis.

Results and Discussion

Finding Optimum Perforation

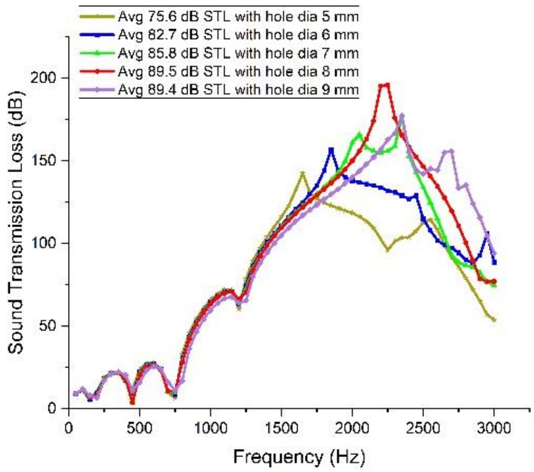

Figure 4. STL Analysis at various hole diameter.

The muffler was initially designed with a fixed dimension consisting of three baffles placed at different positions and perforation in the inlet and outlet pipes. The centre, outlet, and inlet pipe's diameter of holes were altered while the number of holes remained constant. During this time, it was observed that when the diameter of the hole was kept at 5 mm, the sound transmission loss

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was 75.6 dB. After this, when the diameter of the hole was kept at 6 mm, the sound transmission loss was 82.7 dB, similarly at 7 mm, the sound transmission loss was 85.8 dB, It was 89.5 dB at 8 mm hole diameter and 89.4 dB at 9 mm hole diameter, which was lower than before. In this entire analysis, the highest sound transmission found with a hole of 8 mm diameter was 89.5 dB. Further analysis has been done, taking this design as the basis.

Effect of the Fourth Baffle

Further analysis considered the hole with an 8 mm diameter as the basis. In further analysis, sound transmission loss has been calculated by installing the fourth baffle at different places in the muffler.

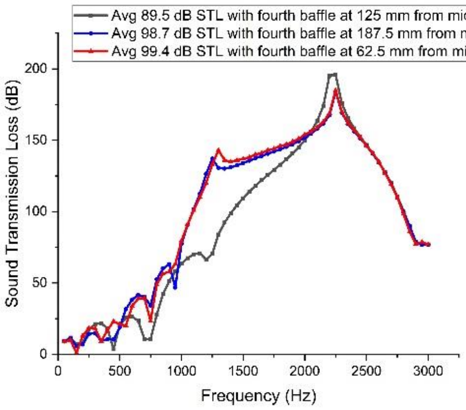

Figure 5. STL Analysis with Fourth Baffle.

It was observed that when the fourth baffle was installed at a distance of 187.5 mm from the central neutral axis of the muffler, the sound transmission loss was 98.7 dB, while when it was installed at a distance of 125 mm from the central neutral axis, the sound transmission loss was 89.5 dB, which was less than earlier condition. After this, when the fourth baffle was installed at a distance of 62.5 mm from the central neutral axis, the maximum sound transmission loss was obtained, which was 99.4 dB. Also, it was the highest in all three cases. Further analysis was carried out with the muffler design with 99.4 dB of sound transmission loss.

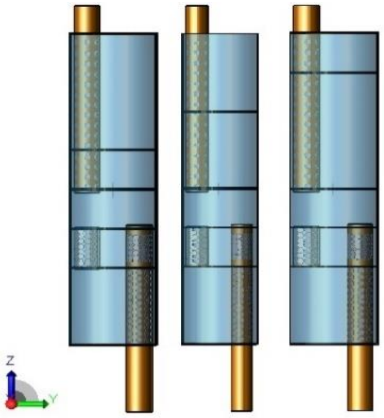

Figure 6. Schematic view of the muffler with the fourth baffle at various positions.

Effect of Various Sound Absorbing Material

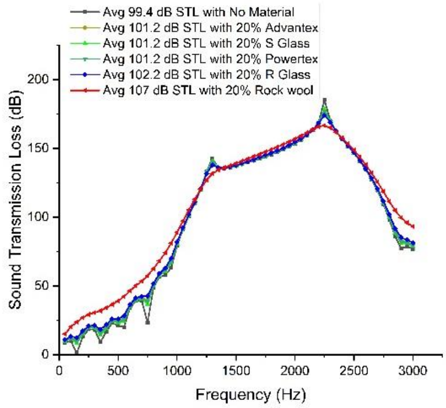

Figure 7. Effect of various sound-absorbing materials with filling densities of 20%.

The final design obtained in the muffler analysis was filled with different sound-absorbing materials with 20% density along with the fourth baffle and the sound transmission loss was measured. When filled with Advantex, it was observed that the sound transmission loss was 101.2 dB. With S-Glass and Power tex, it was also 101.2 dB. When the muffler was filled with R-Glass with 20% density, the sound transmission loss increased to 102.2 dB. Finally, the highest sound transmission loss was obtained with rock wool, which was 107 dB.

Testing and Validation

As shown in figure 8, this experimental arrangement contains numerous extra elements in addition to the hybrid absorptive muffler. These include a speaker with an AU-60 capacity, two microphones, and a predetermined load. Then, an amplifier, a sound analyzer, and specialised software are connected to this arrangement. The experiment is carried out over a frequency range of 50 to 3000 Hz.

Figure 8. Schematic view of experimental setup.

As shown in Figure 8, measurements are made at two different places, 1-1' and 4-4', to adequately cover this frequency range. The selected sites 1-2-3-4 are used to monitor pressure in the frequency range of 50 to 400 Hz.

In contrast, the 400 to 3000 Hz frequency range is used to measure pressure at sites 1'-2'-3' and 4'.

Figure 9. Sound-absorbing materials were used during validation.

A circular exhaust system consists of an external cylindrical tube and an internal perforated tube positioned coaxially. The two ends of the outside cylindrical chamber are covered by two circular flanges that are put on the interior tube. The expansion chamber measures 500 mm in length and 130 mm in diameter in the test setup, which also comprises a perforated pipe with an internal diameter of 35 mm. Rock wool and glass fibre have been selected as the two materials to perform sound transmission loss. As shown in Figure 9, it is now packed with different packing densities, including 60 kg/m3, 80 kg/m3, and 100 kg/m3.

The comparative examination of sound transmission loss between two materials—(a) glass wool and (b) rock wool—is shown visually in Figure 10, which is shown above. One-dimensional wave analysis and experimental validation both support this analysis, which is done at the same intensity level. A different set of design criteria can be used to imitate the one-dimensional wave analysis.

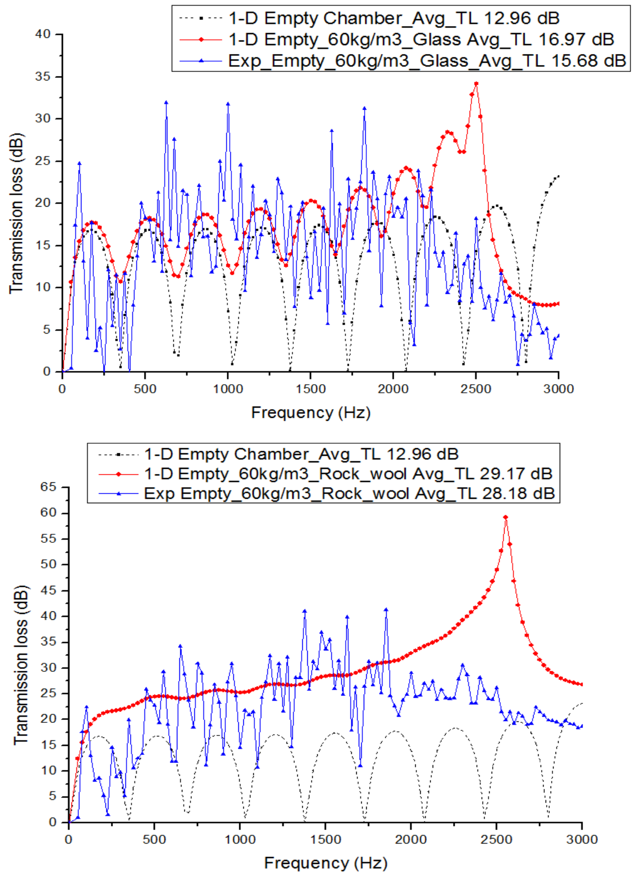

Figure 10. Compression of STL with Glass Woll and Rock Woll Materials and Methods.

Conclusion

The experimental and simulated sound transmission loss outcomes were correlated with an inaccuracy of 2.4%. The sound transmission loss curve shows strong agreement between experiment and models for a simple design like the expansion chamber. Sound transmission loss was measured by making holes of different diameters on the inlet, outlet, and middle pipe of the muffler, in which the optimum condition was found with an 8 mm hole, in which the highest sound transmission loss was found, which was 89.5 dB. When the fourth baffle was added to the muffler at different positions, it was observed that when installed at a distance of 62.5 mm from the neutral axis of the muffler, an increase in sound transmission loss was observed, which was 99.4 dB. In the end, the final muffler design was filled with different sound-absorbing materials, and which the highest sound transmission loss observed was found when filled with Rok Wool, which was 107 dB with 20% density.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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