Experimental and numerical investigation of transmission loss in a zero-flow silencer

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ABSTRACT

To evaluate the acoustic performance of the muffler at zero-flow, different methods of determining transmission loss (*TL*) were studied. Numerical and experimental approaches were used to calculate *TL*. The numerical method employed was the Herschel-Quincke tube method (case 1) COMSOL simulation (case 2) and ANSYS simulation (case 3). The experimental approach utilized the transfer matrix method with the aid of software developed by the B&K software (case 4) and the sound card with MATLAB software (case 5) was used to calculate *TL*. Furthermore, the mesh independence of numerical methods and the uncertainty of the experimental method were examined. Results were evaluated between 20 and 1900 Hz, which is an appropriate frequency range for *TL* calculations. According to the results, the equivalent *TL* for cases 1 to 5 is approximately 5.81 dB, 5.35 dB, 5.21 dB, 4.08 dB, and 3.77 dB, respectively. Based on the findings, it can be concluded that the equivalent *TL* of ANSYS and COMSOL simulations was similar, and COMSOL simulation results in a 8% lower equivalent *TL* than the case 1 approach. Similarly, the equivalent *TL* of experimental calculation methods indicates that the case 5 approach has a 7.5% lower equivalent *TL* than the case 4 approach.

KEYWORDS

Acoustic, Muffler, Silencer, Experimental Study, Simulation

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1. Introduction

The main function of a silencer is to reduce the sound pressure level along the flow between the internal and external sides of the fluid flow duct. Silencers are broadly categorized into two types: passive silencers and active silencers. Passive silencers, also known as mufflers, are further divided into reactive and absorptive types.

Kalita & Singh [1] presented an experimental method based on Taguchi principles for optimizing the design and enhancing the performance of mufflers. The results obtained for the optimized muffler through simulations in the commercial software COMSOL and the aforementioned experiments were compared with the initial muffler's transmission loss (*TL)* values. The optimized mufflers showed significant improvement in maximum *TL* and overall performance across an extended frequency band. In the simulation model, the maximum *TL* increased from 71.04 dB to 73.33 dB, with experimental results showing an increase from 69.26 dB to 72.94 dB. Gavit and Wani [2], in their study of reactive automotive mufflers, managed to significantly eliminate the interference caused by engine exhaust sound waves. To reduce design complexity, CAE modeling and analysis were performed. The *TL* was also considered as a spectrum of frequency functions based on its overall RMS, known as RMSTL, in the mentioned study. A genetic algorithm was used to optimize the variables. The results indicate that in the optimized dimensions, the maximum *TL* increases by 10.24 dB. The RMSTL value obtained for the optimized muffler is 23.04 dB, compared to 20.9 dB for the initial muffler. The maximum *TL* for the initial muffler is 85 dB, while it is 90.05 dB for the optimized muffler. Sonkule et al. [3] conducted theoretical analysis, finite element method (COMSOL), and experimental validation using a two-load method to evaluate the *TL* of a single-chamber reactive muffler. In the theoretical analysis, MATLAB software was used based on the empirical relationship of *TL*. It is noteworthy that their numerical and experimental analysis results are in good agreement.

The aim of this paper is to measure and calculate *TL* in a zero-flow using numerical and experimental methods. This study examines the use of a hybrid method based on a computer sound card for acoustic information processing instead of laboratory equipment, with calculations performed in MATLAB. This method facilitates easier and more cost-effective execution of experimental research activities.

2. Numerical methods

2.1 Herschel–Quincke Tube Method (1D Numerical)

The Herschel–Quincke tube consists of two parallel tubes with specified lengths and cross-sections. In this method, a one-dimensional solution is obtained considering a planar acoustic wave. All acoustic elements are assumed to be tubes, and their geometric complexity is accounted for by increasing the tube length [4]. By writing the mass conservation equations and the equality of acoustic pressure and assuming equal lengths of the two tubes between each intersection, the *TL* in a simple muffler can be determined.

2.2 Finite Element Method (FEM)

2.2.1 COMSOL

The numerical simulation in this paper was conducted using COMSOL 5.5 Multiphysics software based on FEM. The performance of the muffler was examined in three distinct positions based on their geometric shapes. The frequency range considered was between 20 to 2000 Hz. The Pressure Acoustic, Frequency Domain module was used in this study.

2.2.2 ANSYS

Another simulation was performed using ANSYS 2021 R2 software with the Harmonic Acoustic module based on FEM in a three-dimensional format. The acoustic impedance for the inlet pipe of the muffler was assumed to be constant. The frequency range considered was between 20 to 2000 Hz.

3. Transfer Matrix Method for Experimental Measurement

In this method, two pairs of microphones are used on both sides of the muffler. The impedance tube measurement method was followed in the experimental stages of this research. In most acoustic studies, the results of tests related to this equipment are significant due to the determination of the inherent acoustic properties of the studied element.

4. Methods for Analyzing Experimental Data Obtained in This Research

In this research, two approaches were utilized: first based on the commercial hardware and software from B&K, and the second based on a sound card and MATLAB software.

a. B&K Software
b. Computer Sound Card and MATLAB Software

5. Results and discussion

The simulation results in COMSOL and ANSYS also show the *TL* versus the frequency spectrum of the full octave in Figure1, demonstrating a consistent oscillatory behavior similar to the results of other references [5, 6]. This simulation is characterized by five oscillatory peaks without point oscillations and with slightly less intensity than the 1-D case and maximum oscillations at the final frequency. Although the trend in the final frequency shows an increasing trend and a slightly upward trend is observed at the oscillation peak, the peak of the first peak (in the 200 Hz range) shows an increase of about 2 dB with the fifth peak (in the 1600 Hz range). Figure1 compares the *TL* values in the experimental results for the muffler, indicating that these results best match the experimental data obtained from the B&K microphone and the computer sound card. It is suggested that this combined approach be used for similar experimental investigations.

Tables1 summarize the equivalent *TL* for different methods of calculating muffler *TL*. The equivalent *TL* for the one-dimensional simulation and the simulations in COMSOL and ANSYS are 5.81 dB, 5.35 dB, and 5.21 dB, respectively. The COMSOL simulation shows an 8% reduction in equivalent *TL* compared to the 1-D simulation. Additionally, the equivalent *TL* obtained in the ANSYS simulation is 2.6% lower than that of COMSOL. The equivalent *TL* for the B&K software approach and the sound card approach are 4.08 dB and 3.77 dB, respectively, with the sound card approach showing 7.5% less *TL* than the B&K software approach. Finally, a comparison of the experimental approaches and the COMSOL simulation shows that the equivalent *TL* for the B&K software and sound card approaches is 23% and 30% less than that of the COMSOL simulation, respectively.

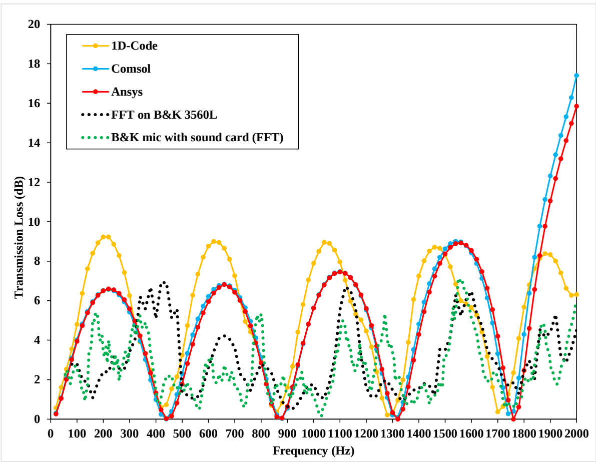

Fig.1.Spectral diagram of muffler Transmission Loss for one-dimensional method, COMSOL, ANSYS simulations and experimental results

Table.1. Equivalent Transmission Loss of different approaches and their percentage changes

Method	Description	TL_{eq} (dB)
Approach-1	Herschel–Quincke Tube Method	5.81
Approach-2	COMSOL Simulation	5.35
Approach-3	ANSYS Simulation	5.21
Approach-4	B&K Software	4.08
Approach-5	Sound Card & MATLAB	3.77

6. Conclusion

Considering the comparison of the three numerical methods performed, Approach 2 (COMSOL simulation) is selected as the appropriate approach due to its high accuracy and short time. In other words, since the COMSOL software has much better compatibility with different and irregular meshes compared to ANSYS, and its suitable environment for multiphysics solutions and combining acoustics with fluid flow, which uses Linearized Navier-Stokes (LNS) equations to solve acoustic and fluid equations simultaneously, this software is recommended as the selected numerical method in the article. Approach 5 (computer sound card and MATLAB software) is also selected as an appropriate and low-cost experimental method for extracting and processing acoustic.

7. References

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