A Review on Transmission Loss of the Silencer

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Abstract: *The study highlights the exhaust system as a major contributor to noise pollution in urban environments. It emphasizes the untreated exhaust noise as a significant source, often surpassing the combined structural noise levels. The parameters Transmission Loss (TL) and Insertion Loss (IL) are introduced for characterizing muffler performance, with TL focusing solely on the muffler's performance and IL providing more accurate measurements in real operating conditions. This paper acknowledges the complexity of commercial mufflers and the classification into dissipative and reflective types, emphasizing the need for accurate prediction of sound radiation in reactive mufflers. It underscores the use of TL as a commonly employed parameter for evaluating muffler sound radiation, which can be easily predicted using known physical parameters. Lastly, it briefly mentions a study that improved transmission line theory for designing an expansion chamber muffler in a helicopter application.*

Keywords:*Exhaust system, Noise pollution, Untreated exhaust noise, Transmission Loss (TL), Muffler performance.*

I.INTRODUCTION

Noise from the automobile is generated by several sources such as the internal combustion engine, the brake system, the inlet and exhaust system and the flow around the body of the automobile. The researches paid attention to the exhaust system which is believed to be one of the main factors of noise pollution of the urban environment. Intake and exhaust system noise draws a huge contribution to the interior and exterior noise of cars. Exhaust system contributes the major noise of automobiles. Untreated exhaust noise often exceeds all system structural noise by a factor of ten in terms of sound pressure levels. In order to anticipate muffler performance, there has been a lot of study and development.The Transmission Loss (TL) or Insertion Loss (IL) of the muffler, from the designer's perspective, characterizes muffler performance. The transmission loss is defined as the difference between the sound power of the transmitted pressure wave at the muffler's outlet and the sound power of the incident (progressive) pressure wave at the muffler's intake. The advantage of using TL is that source or terminal attributes are not required because it is a parameter of the muffler alone. Because of the simplifications, the TL is the most common parameter for muffler performance. The difference between the acoustic pressure radiated from the source with and without the attached muffler is known as insertion loss. The IL measures muffler performance under real-world conditions while taking into account the source characteristics making it a more accurate means of doing so. The commercial car mufflers often have a complex shape with numerous connected pieces and complex acoustic components. Dissipative and reflecting mufflers are the two main classifications that are used in the industry. The foundation of a dissipative muffler is the idea that heat can be produced by converting the energy of exhaust noise brought on by varying pressure waves. This is done using sound-absorbing materials such as porous sound attenuating woven fibres and perforated tubing. Another benefit of dissipative mufflers is that the pressure drop across the system is relatively low because the flow path is not significantly altered by flow reversals, twists and turns, or by any other means. Reactive silencers generally consist of several chambers and tubes. Those configurations can provide effective noise attenuation at lower frequencies but fail to attenuate higher-frequency noise and usually produce a high pressure drop due to the presence of baffles and flow reversals [1].

Transmission loss (TL) is often measured using the three point (decomposition method) or four pole methods; the four pole method is executed by a two-source method and a two-load method. Boundary element methods (BEM) with Coasty and the transfer matrix approach with Ricardo wave are two numerical techniques applied to model transmission loss in exhaust mufflers. Both Ricardo wave and ComsolMultiphysics were used in the current investigation to forecast transmission loss. Ricardo-Wave is a one-dimensional gas dynamics code based on finite volume method for simulating engine cycle performance. It is widely used by automotive and exhaust manufacturers such as Eberspächer. Also, COMSOL Multiphysics Modelling Software is known to the capability to model transmission loss of different mufflers such as reactive, absorptive and hydride mufflers. As a result, COMSOL Multiphysics and Ricardo-wave have been proposed for the transmission prediction [2].

A. Mufflers

The muffler – it's the last component of your exhaust system, yet first in the hearts of many ―mod crazy‖ car enthusiasts. The average muffler performs its function discretely and, quite literally, under the radar. It is said that it is always heard before it is seen (unless your muffler is truly whisper-quiet). It's barely above the road and is so far under the radar.The muffler is one of the most altered, adjusted, tweaked, relocated, redesigned, rigged, mended, and ready-for-anything components. Even beginners don't mind tinkering with the muffler's position and functionality; experts adore designing them. In addition to improving sound, muffler upgrades can also boost your car's horsepower and engine economy with a few subtle modifications. This unsung hero, which should not sing, is traveling with you in order to conceal the under-body sounds of your car. It also has a huge responsibility. The muffler is the ultimate final filter. How important is the muffler? Well, consider its position in the grand scheme of things. It's the last component before all of your cars ―input‖ becomes ―output [3].

The main Functions of Muffler are – as shown in figure 1.

•Bear in mind that the combustion process is a series of explosions that produces allot of noise.
•Mufflers serve to keep the exhaust quiet to acceptable levels.
•Some mufflers also use fiberglass packing that absorbs the sound energy as the gases flow through.
•Most mufflers use baffles to bounce the exhaust around sending off the energy and quieting the noise.

Figure 1. Muffler

B. Types of muffler

Typically mufflers are classified under two categories, dissipative and reflective.

- **Dissipative Muffler:-** The concept behind a dissipative muffler is to generate heat from the exhaust noise energy brought on by fluctuating pressure waves.
- **Reflective Muffler:-** This kind of muffler tries to eliminate the progressive pressure wave by using the geometry of the intricate muffler components to produce impedance mismatches with the entering exhaust stream.

C. Silencer Design & Efficiency

Designing a silencer to control the sound of a sound generating device is a complex process that affects the volume and aerodynamic efficiency of the device. The important criteria in the design of the expansion silencer include minimum sound reduction in the desired frequency range, pressure loss, geometry and maximum volume, strength and economic aspects. Basically, the acoustic performance of silencers is characterized by parameters such as insertion loss (IL), transmission loss (TL), noise reduction rate (NR) and aerodynamic performance (pressure loss) by measuring the total air flow pressure. The best and one of the most common parameters used to evaluate the acoustic properties of a silencer is the transmission loss (TL). The transmission loss can be predicted using the dimensions and physical parameters of the silencer. There are different methods such as analytical methods and numerical solution methods to evaluate sound transmission loss and pressure loss of silencers [4]

One of the ways to increase the transmission loss of simple expansion silencers (Figure 3) is to increase the cross-sectional area of the expansion chamber compared to the cross-sectional area of the inlet pipe. Lower frequencies are transmitted and reduce the performance of the silencer in the frequency range. Therefore, to achieve optimal sound reduction, the ratio of the surface of the expansion chamber to the surface of the inlet pipe should be considered in the calculations. As shown in fig. 2

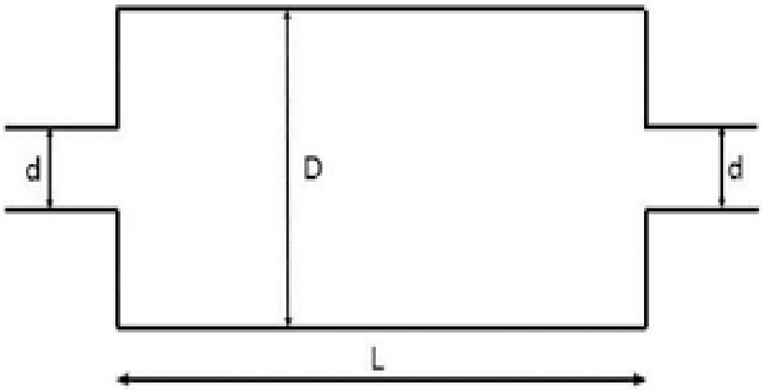

Figure 2. Simple expansion silencer

II. TRANSMISSION LOSS (TL)

The design of an au tomobile's exhaust system depends heavily on the accurate modeling of the sound radiation properties of reactive mufflers. The most commonly used parameter to evaluate the sound Current Research Trends in Sound Transmission Loss of Silencers radiation characteristics of muffler is sound transmission loss (TL). Due to the ease with which it can be predicted from the known physical characteristics of the muffler, transmission loss is one of the most often used performance metrics. The transmission loss characteristics of a muffler can be simulated using a variety of methods. Complexity and presumptions vary among them. But once developed, analytical models quickly and accurately use the generated formula to produce results, particularly in the low and mid frequency band. Such a developed formula can be very useful to represent performance characteristics of the muffler for relative comparison of design alternatives at design stage.The authors in [5] improved a standard transmission line theory for designing an expansion chamber muffler as an application of helicopter. A computerized method using EXRSIL and FORTRAN was used. In order to achieve the lowest transmission loss across a given frequency range, they performed an optimization technique that modifies the lengths of the muffler component. The results showed that a three-stage expansion chamber muffler used in conjunction with an exhaust pipe-Y-connector to combine the exhaust gases from all cylinders decreased exhaust noise without significantly affecting engine performance. Investigations for passive mufflers using experimentation and mathematics. For numerically simulating and forecasting such mufflers, the multi domain boundary element method (BEM) is used. Experiments were performed to estimate the propagation constant and the perforate transfer impedance in order to properly incorporate perforates and sound absorbent materials in boundary element models. Analytical one-dimensional solutions were used to obtain the TL of reactive and dissipative mufflers, validating the BEM. They discussed about a number of TL determination methods. It was found that an excellent results were found between experimental and boundary element method.

Development a formula for predicting transmission loss (TL) of a long rigid duct was conducted [6]. By adding some improvements like Helmholtz resonator, experimentally great results were obtained. They concluded that the acoustic interaction between two acoustic filters can be ignored if the distance between them is great enough.In the previous in [7], it has been the graphical analysis of optimal shape designs was discussed in order to improve the performance of sound transmission loss (TL) on a constrained single expansion muffler. Typically mufflers are classified under two different categories, dissipative and reflective. In [8], it has been presented optimal design of a single chamber muffler with side inlet/outlet. They described both the graphic analysis and the computer aided numerical assessment. They obtained the results and then verify them with Kuhn-tucker condition for accuracy. The simulated results showed that STL of muffler is exactly maximized at the desired frequency. Through experimental, analytical, and BEM analysis of a hybrid concept, the acoustic performance of a single pass perforated silencer was investigated [9]. Variations in the outer diameter and material density were investigated on a single-chamber dissipative silencer. They noticed that as density increased, resonance frequency and transmission loss also did as well. By increasing the outer diameter, the lower resonance frequency can be reduced once again, unlike reactive chambers, which can raise the peak amplitude of the TL. Additionally, it was discovered that the three-dimensional BEM results agreed with those of the experiments. Two dissipative chambers and a reactive element boost TL, creating an efficient hybrid silencer. There is still more research to be done on the impacts of partial fiber filling, location, reactive chamber shape, and perforations distribution. In [10], it has been Discussed two measurements that don't require anechoic termination. The methods were the two load and two source methods, both were demonstrated on two muffler types, simple and double expansion chambers. The results of the BEM results were compared to the measured TL. The measured TL for both techniques demonstrates that TL may be accurately estimated without an anechoic termination.

II. LITERATURE REVIEW

Ranjbar, M., &Alinaghi, M. (2016). [11]Many companies find it difficult to reduce the noise pollution that engines' exhaust systems develop. Mufflers have been used during this situation to lessen the noise that automobiles' engines emit into the environment. Mufflers are made to reflect the engine's sound waves in a way that causes them to partially cancel one another out. The geometry of the muffler affects how much noise is transmitted. As a result, it is essential to do research on how to maximize noise transmission loss in mufflers utilizing the form modification approach. The maximizing of noise transmission in mufflers is researched and analyzed in this work. To demonstrate the absorptive muffler, a model is created. Shell elements are used in the modeling of the muffler structure and its sound-absorbing layer. In this model, the muffler structure is examined in relation to how it affects transmission loss (TL). The outcomes are contrasted against a model devoid of an absorbing layer. It suggests that the degree of noise transmission loss of the muffler over a wide frequency range depends significantly on the thickness and material type of the absorbing layer.

X. Hua, et. al. (2015) [12]To calculate a muffler or silencer's transmission loss, both the two-load and two-source approaches are frequently utilized. If one of the impedance tubes that are available for purchase is used, the two-load approach is more frequently used. Therefore, the goal of the study presented is to define best practices for impedance tube set ups when implementing the two-load approach. To begin with, conical adapters may be utilized in some cases to connect impedance tubes to the muffler. The effect of adding conical adapters at low frequencies is shown to be significant, especially if the adapter is short in length. By using measurement and plane wave theory, the impact of modifying the adapter's length was investigated. Second, the decision-making process for choosing the algorithm to compute transmission loss is examined. One method for calculating transmission loss is to first compute the scattering or transfer matrices. It is demonstrated that either approach yields results that are as satisfactory when measurements are taken simultaneously with four microphones. However, it is demonstrated that if only two microphones are utilized, the reference microphone selection is more crucial. In that situation, it was discovered that measurements are enhanced when a downstream microphone is used as the reference rather than an upstream microphone. An error analysis was carried out to verify this, and an explanation is offered.

Longyang Xiang, et. al. (2017) [13]The blower utilized in fuel cell vehicles' engines has its noise behavior evaluated and examined. Multi-chamber micro-perforated muffler with adjustable transmission loss is suggested as a noise-canceling solution based on noise characteristics. By altering the length of the third chamber, the correction is accomplished. The muffler resonant frequency and chamber length relationship model is fitted. The muffler sample is also created for an experiment. The study found that the narrow band harmonics with a frequency range of 2000-3500 Hz and the wide band noise with a frequency range of 500–1000 Hz are both present in the blower noise. The experimental findings demonstrate the effectiveness and efficiency of the suggested muffler in attenuating both the narrow band harmonics and the wide band noise at low to medium frequencies.

Wang, Y., et. al. (2021) [14]Inherent output flow pulsation is a characteristic of hydraulic pumps, which are positive displacement pumps. Upon coming into contact with liquid resistance, flow pulsation causes pressure pulsation. Pressure pulsation propagates through the pipeline and can result in pipeline rupture and serious safety incidents, as well as vibration, noise, damage, and even pipeline rupture. The application and development of airborne hydraulic systems are severely constrained by the hazards of vibration and noise induced by pressure pulsation, which are compounded with the development of airborne hydraulic systems with high pressure, power, and flow rate. This review study analyzes pressure pulsation in hydraulic systems and examines its mechanism, effects, and method of suppression. After that, pulsation attenuators are categorized and explained in terms of their properties based on several operating principles. In addition, a preliminary design technique for pulsation attenuators as well as the crucial technologies of simulation design and matching with airborne piston pumps are proposed. Finally, the future of pulsation attenuators is predicted. This document serves as a resource for the study and use of pressure pulsation attenuators.

L. Yang, et. al. (2015) [15]Bar silencers used in industry may consist of a large array of rectangular or round bars packed in a rectangular lattice arrangement. Due to the size of the lattice, normally only a single unit that represents a building block for the lattice is isolated for analysis purposes. The plane-wave cutoff frequency can be quite low even with just one isolated unit, although the inlet and output are still relatively big. The transmission loss must therefore be calculated taking higher-order modes into account at the intake and output. For the purpose of calculating transmission loss, this study applies the recently created "impedance-to-scattering matrix method" to transform the element-based impedance matrix into the mode-based scattering matrix. Finding an analytical expression of the modes required for the modal expansion may not always be attainable depending on the shape of the inlet and output. The eigenvalues and eigenvectors of the inlet/outlet cross section are extracted in this study using the two-dimensional finite element approach.The impedance matrix is then transformed into the scattering matrix via the modal expansion using the eigenvectors. Numerous inlet and outlet configurations, including triangular, circular, and rectangular cross sections, are included in the test cases.

Elsayed, A., et. al. (2017)[16]Baffles are used in exhaust mufflers because they are believed to enhance transmission loss and lessen noise emissions. This study makes the assumption that baffle cut ratio has a similar effect on muffler performance as a shell-and-tube heat exchanger, so it seems sense that baffle cut ratio would have an impact on muffler performance. A parametric analysis of the impact of baffle arrangement on anticipated transmission loss and pressure drop is presented in this paper. Investigations were conducted on the impact of baffle cut ratio, baffle spacing, baffle hole count, and hole pattern distribution on transmission loss. The findings demonstrated that decreasing the baffle cut ratio increased the transmission loss at middle frequencies by up to 45% while reducing the distance between muffler plates improved the muffler transmission loss by 40%. The baffle effect on flow was evaluated using a thermal baffle approach model, and the results showed that when the baffle cut ratio changed from 75% to 25, there was a sharp 15% decrease in fluid temperature in the direction of axial flow. The impact of baffle cut ratio arrangement on acoustic response and back pressure has not, to the authors' knowledge, been previously documented or studied.

IV. ADVANTAGES AND DISADVANTAGES SILENCER

A. Advantages

Noise Reduction: The primary advantage of a silencer is its ability to reduce the transmission of noise from a noise source, such as an engine or industrial equipment. It helps to attenuate the sound waves generated by the source, resulting in a quieter environment.

Compliance with Regulations: Silencers play a crucial role in meeting noise regulations and standards imposed by local authorities and regulatory bodies. By effectively reducing the noise emitted from machinery or equipment, silencers help organizations maintain compliance and avoid penalties.

Improved Working Conditions: By reducing the noise levels in industrial or commercial settings, silencers contribute to improved working conditions for employees. Lower noise levels can lead to increased productivity, reduced stress, and improved concentration among workers.

Environmental Impact: Silencers also have a positive environmental impact by reducing noise pollution. Excessive noise can have detrimental effects on wildlife, ecosystems, and nearby residential areas. By controlling noise emissions, silencers help protect the environment and promote a more sustainable approach.

B. Disadvantages

Incre ased Back Pressure: Silencers can introduce back pressure into the system, which can have a negative impact on engine or equipment performance. Higher back pressure can lead to reduced power output, increased fuel consumption, and decreased overall efficiency.

Size and Weight: Depending on the application and required noise reduction levels, silencers can be bulky and heavy. This can pose challenges in installations where space and weight restrictions are present, such as in automotive or aerospace applications.

Cost: High-quality silencers that offer significant noise reduction capabilities can be expensive, especially when custom designs or specialized materials are required. The cost of implementing silencers may be a significant factor, particularly for smaller businesses or projects with tight budgets.

Maintenance and Service: Silencers may require regular maintenance and cleaning to ensure optimal performance. Accumulated debris, such as soot or particulate matter, can impact the effectiveness of the silencer and increase pressure drop over time. Regular inspection and servicing are necessary to maintain performance levels.

Design Limitations: Silencer design is a complex process that requires careful consideration of factors such as space restrictions, acoustic performance requirements, and system integration. Design limitations may arise when attempting to achieve specific noise reduction targets while balancing other constraints, leading to compromises in overall performance.

It is important to note that the advantages and disadvantages mentioned above are general points and may vary depending on the specific type of silencer, application, and operating conditions.

V. CONCLUSION

This review paper highlights the exhaust system as a major contributor to noise pollution in urban environments, with untreated exhaust noise surpassing structural noise levels. It introduces Transmission Loss (TL) and Insertion Loss (IL) as parameters for evaluating muffler performance. The paper emphasizes the complexity of commercial mufflers and the importance of accurate sound radiation prediction in reactive mufflers. TL is commonly used to assess muffler sound radiation and can be easily predicted using known physical parameters. Furthermore, it briefly mentions a study that improved transmission line theory for designing an expansion chamber muffler in a helicopter application. The paper emphasizes the need for effective noise reduction strategies and advancements in muffler design to mitigate noise pollution from exhaust systems.

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