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SIMULATING NOISE FOR ACOUSTIC PERFORMANCE MAXIMIZING EFFICIENCY OF EXHAUST SILENCER WEIGHT AND SIZE

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ABSTRACT: In the highly competitive automotive business, there is a growing emphasis on developing new car models that are lighter and more cost-effective. As a result, every aspect of the car's systems is carefully optimized to reduce weight while still meeting the necessary performance standards. The exhaust system is a crucial component of the car, responsible for minimizing engine noise to acceptable levels and ensuring compliance with BP (backpressure) standards for optimal engine functioning. Optimizing the vehicle silencer system for size and weight reduction while simultaneously ensuring NVH performance, meeting backpressure requirements, and satisfying customer expectations of sound quality is a challenging task. This requires a complete overhaul of the silencer, which is highly intricate. This study aims to improve the muffler of a gasoline-powered vehicle by analyzing its acoustic performance using noise simulation. The examination and comparisons were conducted using the Transmission Loss (TL), which represents the silencer's ability to reduce sound. An evaluation was conducted on the primary muffler to measure its transmission loss (TL) and back pressure (BP). The design iterations for the interior components of the silencer have been finalized, and the transmission loss (TL) and back pressure (BP) have been predicted. The design option that corresponds to the baseline silencer performance was selected for the creation of the prototype and further experimental validation. The enhanced suppressor was verified using real-time measurements of TL (Transmission Loss) and BP (Back Pressure).Comparisons against anticipated performance indicated that the altered silencer achieved the same level of performance as the original. This method can also be employed to expedite the design cycle time throughout the existing design phases.

Key words-Exhaust, Muffler, Acoustics, Attenuation, BP (Back Pressure), IL (Insertion loss),NVH (NoiseVibrationHarshness), TL(Transmission Loss)

1. INTRODUCTION

Every year, leading manufacturers release new, lighter, and more powerful variants of popular automobiles. Reasons for this include increased competition and manufacturers' effort to maintain a market footing with innovative goods. Improving vehicle aggregates reduces mass and costs. The exhaust silencer is a critical component. It meets engine BP specifications, reduces vehicle noise to an acceptable level, and conforms with pass-by noise laws. Acoustic and baseline performance are analyzed to optimize silencer design and obtain weight savings. The silencer's most important acoustic properties are transmission loss (TL) and insertion loss.When the tail pipe end is connected to an anechoic chamber, the ratio of incident sound power to transmitted power is TL. To put it another way, the tail pipe does not act as a sound reflector. The term "insertion loss" (IL) refers to the volume difference between

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systems with and without a silencer.The distance from the sensor is utilized to calculate IL.While IL is simple to assess, it is challenging to quantify.For acoustic tests, the silencer's property is TL. Quantifying TL is difficult, but easy to calculate. The TL testing equipment contains both upstream and downstream sound wave tubes.

The acoustic performance of gasoline engine silencers was compared using TL to existing silencers, as well as the BP predicted by analytical methods. To decrease weight, the silencer's design has been internally refined. Internal design improvements to the silencer compared to baseline performance of the TL and BP mufflers. The acoustic modeling tool AVL Boost can predict TL. Optimal alternative for experimental evaluation and prototype development. We compared the measured and projected TL, as well as the silencer's baseline performance. Blood pressure was tested using a portable medical device. We discovered that the expected and actual results were identical.

2. LITERATURE REVIEW

Potente and Daniel researched the fundamental categories of mufflers, as well as the performance standards required for all possible applications. Formula SAE assessed the absorptive muffler type. To achieve the appropriate amount of noise reduction, both an unmuffled and muffled engine were used. In the design of exhaust systems, L. J. Eriksson and P. T. Thawani proved the strong link between theory and practice. Rahman, Sharmin, Hassan, and Nur addressed the design features of a gasoline engine muffler. The muffler's performance features, such as its capacity to reduce noise, have been assessed and compared to those of a traditional muffler. Shital Shah, Hatti, and their team used a pragmatic process to design, develop, and test a reactive muffler for exhaust systems. This unique strategy has various advantages over the traditional way, including a faster product development cycle and improved validation. Jigar Chaudhary has undertaken extensive study on various engine-specific muffler designs and exhaust systems. Munjal, M. L. has provided a comprehensive discussion of the practical design of exhaust and ventilation systems in his textbook. Shubham Pal, Tejpreet Singh Golan, and others revealed a link between insertion loss and resonator length. The persons are Don D. Davis, Jr., George M. Stokes, Dewey Moore, and George Stevens, Jr. The application of the theory to the design of engine exhaust mufflers is depicted graphically in research NACA 1192. Patent US8256569 B1 protects both the apparatus and the method used to reduce exhaust noise. The Internet gives information on the design aspects and sound absorption tactics of mufflers and silencers.Muthukumar, P.S. Yadav, and his colleagues have effectively demonstrated the ability to anticipate muffler performance with the goal of enhancing muffler optimization. A prior study used Transmission Loss to demonstrate how the Computational Fluid Dynamics (CFD) approach may be used to forecast the performance of a compressor muffler [13]. Rahul et al. (2014) suggested a mathematical approach to investigate transmission loss using MATLAB. According to the research findings, implementing pipe protrusions at both the intake and exhaust can greatly increase transmission loss. As a result, significant

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research and development efforts have been made to anticipate muffler performance.

Mufflers are generally divided into two types: dissipative and reflective. Dissipative mufflers turn exhaust sound energy into thermal energy. Materials with sound-absorbing properties, such as glass fiber, absorb sound. There is a minimal decrease in pressure. Reflective mufflers consist of multiple chambers and tubing. The attenuation performs well at lower frequencies but falls short of expectations at higher frequencies. Furthermore, the majority of the pressure decrease can be attributable to the presence of baffles and flow reversals.

The transmission loss (TL) is the key parameter used to assess muffler performance in terms of sound radiation. Regarding the determination of TL when flow is present: In 2011, Hyunsu Kim created a flow impedance tube arrangement that utilized burst signals. The TL can be easily determined by examining the muffler's tangible qualities. In 1973, Parrot et al. built on a conventional transmission line theory to create a design for a helicopter-specific expansion chamber exhaust. Amiya and Mohanty's 1993 experiments and computer studies focused on passive mufflers. The multidomain boundary element approach (BEM) was used to mimic mufflers and forecast transmission loss. In their 1998 study, Chen et al. aimed to create a formula that could reliably forecast the transmission loss (TL) of a long rigid duct. Yeh et al. (2003) conducted a graphical analysis of optimal shape designs for transmission lines (TLs) operating in constrained single expansion chambers with the goal of enhancing performance. Yeh et al. (2004) proposed an ideal layout for a single chamber muffler that included a side intake and outlet in their study.

Selamet et al. (2003) investigated the acoustic performance of a single-pass perforated suppressor, using experimental, analytical, and boundary element method (BEM) methodologies. Z. Tao and A. Seybert studied two measurement procedures that did not require anechoic termination. To illustrate the two masses and two sources, two mufflers were used, one with a simple design and the other with a double expansion chamber. Besache et al. (2006) assessed a three-dimensional resonator with perforated ducts for acoustic diffraction. In 2007, Mihai Bugaru and OvidueVasili used the transfer matrix technique (TMM) to model mufflers. The methodologies for forecasting TL were defined in accordance with the TMM principles. Florent Masson and his colleagues conducted an experiment in 2008 to examine whether micro perforated panels (MPP) may be used to improve the acoustic performance of mufflers while lowering costs. Rahul Bansal did research in 2005 on the acoustic properties of perforated chattered material within a duct using random sound.

In 2009, Yoon Young Kim and Jin Woo Lee optimized partition layouts within a muffler's expansion chamber. To improve the transmission loss (TL) at specific frequencies, an acoustic topology optimization problem formulation was used. To maximise transmission loss (TL) across a broad range of frequencies and optimise the muffler's acoustic profile, In 2010, Thomas and Hikkola took measurements with the goal of refining the design of a muffler by fine-tuning its

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reactive components. Komkin (2010) used TL to improve the muffler's acoustic efficacy. Min-Chie Chiu's 2008 research focused on optimizing the design of multi-chamber plug-inlet mufflers to reduce back pressure. In their work, Key Fonceca de Lima et al. (2011) used parametric form optimization to determine the ideal inlet/outlet duct diameters. Maddali (2011) used parametric studies to evaluate the effect of various parameters on cylindrical muffler configurations.

Wang (2013) evaluated the mufflers' acoustic efficacy, taking into account the interplay of flow rate, temperature, and thermal viscous effects, with the goal of determining transmission loss. Rahul et al. (2014) used MATLAB to explore the transmission line (TL) of a muffler in their study. The finite element modal analysis method was found to have a considerable influence on the muffler's vibration characteristics.

3. TYPES OF SILENCERS AND MUFFLER DESIGN THEORY

The primary function of an automobile exhaust muffler is to reduce noise produced by the engine. Noise is defined as any undesirable or unpleasant sound. Sound is a phenomena that happens when air pressure changes between high and low levels, creating a wave-like pattern of pressure. When the engine's exhaust valve opens, a large amount of high-pressure gas is released into the exhaust system. This causes powerful pressure waves. The sound we hear is created by these high-pressure bursts. As the engine's revolutions per minute (rpm) increase, so do pressure changes, resulting in the production of a high-frequency sound.

The vehicle's muffler must allow exhaust gases to circulate without limiting sound transmission. Mufflers used to suppress unwanted noise are classified into three types: reactive, dissipative, and a combination of the two.

Reactive or reflecting mufflers use destructive interference to reduce noise. A reactive muffler, as shown in Figure 1, typically consists of a series of resonating and expansion chambers designed to reduce sound pressure at specified frequencies. The input and outlet tubes are frequently placed in different positions and include holes that allow sound pulses to travel in multiple directions within a chamber, resulting in destructive interference.

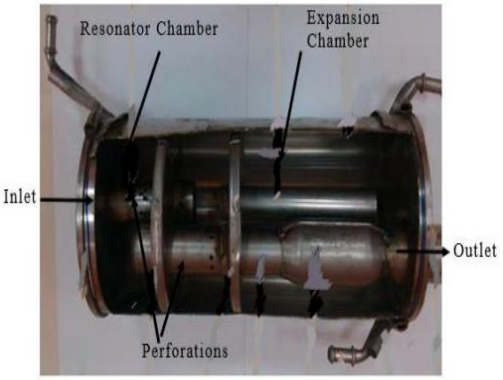


Fig.1ReactiveMuffler

A noise suppressor is illustrated in Figure 2. It either absorbs or disperses sound. The process of absorption diminishes acoustic energy. In the absorbent medium, the energy of sound waves is transformed into thermal energy, which causes a reduction in intensity. A larger steel casing typically encases a straight, circular, perforated conduit that functions as an absorptive muffler. Between the perforated conduit and the casing is a layer of sound-absorbing material that partially absorbs the pressure pulses..

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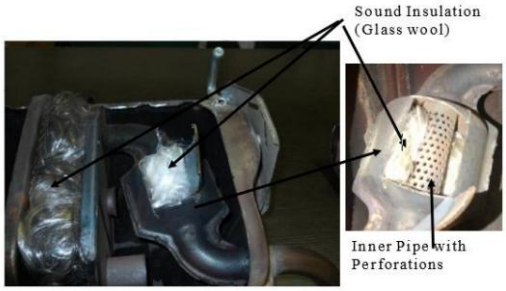


Fig.2AbsorptiveMuffler

Absorptive While reactive mufflers generate more backpressure, they do not provide the same level of noise suppression. To control noise, reactive mufflers often use resonating chambers that focus on specific frequencies. In contrast, absorptive silencers reduce noise across the whole frequency spectrum, with a stronger emphasis on higher frequencies.

It is best to maximize a muffler's performance within the frequency band that corresponds to the engine's peak sound energy. In practice, the sound spectrum of an engine exhaust varies continuously due to its dependence on engine speed, which fluctuates while the vehicle is in motion. While there are numerous techniques to building a muffler for a specific application, the designer has succeeded if the muffler is functional, achieves the necessary noise reduction, and is useful.

The acoustic performance of a muffler is determined by a variety of characteristics. Noise reduction (NR), insertion loss (IL), attenuation (ATT), and transmission loss (TL) are some examples. The difference in sound pressure level over the muffler represents noise reduction. The parameter in question is easily quantifiable but difficult to calculate. Furthermore, its reliability in muffler design is jeopardized because it is dependent on both the termination and the muffler. Insertion loss is the difference in sound pressure level between a location outside the system and one containing and not containing the muffler. The source impedance, radiation impedance, and muffler all have an impact on insertion loss. Despite the fact that insertion loss is simple to measure but difficult to compute, it remains the most relevant statistic for characterizing muffler performance. The problem of producing a perfectly anechoic termination, particularly at low frequencies, makes TL measurement challenging, although TL calculation is simple. Attenuation is measured as the difference between incident and transmitted sound power through the muffler; however, an anechoic termination is not necessary.

Assuming an anechoic termination, the current method for estimating a muffler's transmission loss entails utilizing the plane wave approximation to determine the transmitted power and the incident power using decomposition theory, respectively. Unfortunately, creating a fully anechoic termination is difficult.

4. Design iterations for a muffler with noise modeling.

The TL is computed as follows: TL = 10 log10 (Wi/Wt), where Wi and Wt are the incident and transmitted sound outputs, respectively. The two source and two load approach, unlike the decomposition method, does not require an anechoic termination chamber, and TL measurement is uncomplicated.

Design iterations are carried out using noise simulation to minimize the volume and weight of the baseline mufflers. Figure 3 depicts the baseline and necessary resonator.

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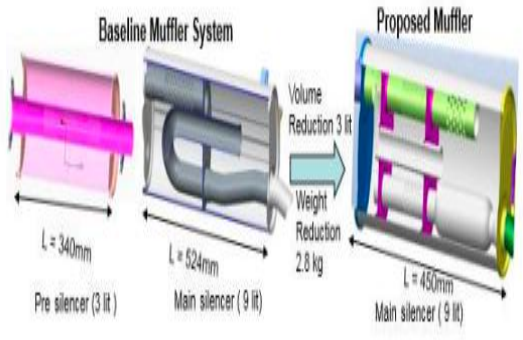


Fig.3Baseline andProposed Muffler

The basic muffler system, including the pre silencer and mail silencer, is modelled in the AVL Boost 1d software, and the simulated TL is displayed in Figure 4.

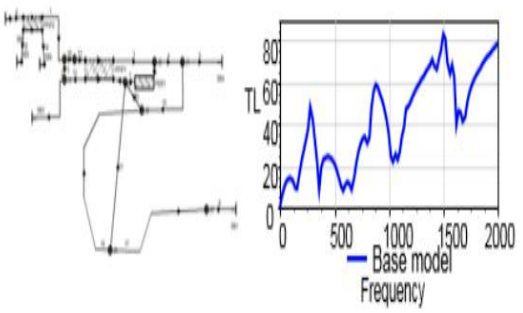


Fig.4AVLBoost1dmodel &TLsimulation of Baseline muffler

Various design iterations were done for the design of the internals of the muffler to achieve the baseline TL performance, as illustrated in fig. 5 and fig. 6.

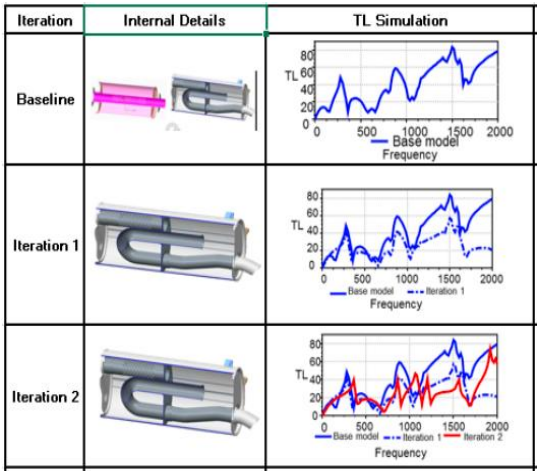


Fig.5ComparisonofDesigniteration 1and2withbaselinemufflersystem

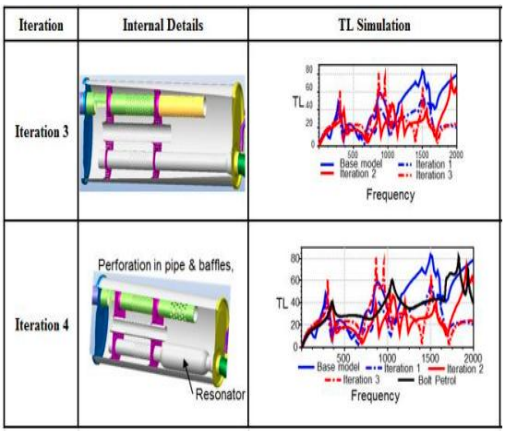


Fig.6SimulationofDesigniteration3and4

The initial iteration was determined by removing the pre-silencer from the baseline muffler. According to the modeling findings, it is evident that the first iteration did not achieve the desired target transmission loss (TL) for the bassline muffler. Consequently, a second round of testing was conducted, resulting in a decrease in the length of the baseline muffler from 524 to 475mm. Nevertheless, the simulation results for TL did not correspond to the baseline muffler TL. Consequently, a third round of iteration was conducted, incorporating novel internal components. Nevertheless, the simulated outcomes for these concepts do not correspond to the standard muffler. Consequently, we introduced the fourth iteration of thoroughly revamped core components. The TL simulation results for these concepts align with those for the standard muffler. Therefore, this design was selected for the actual production of the prototype.

Analytical computation methods were used to predict the back pressure for the stated iterations. The outcomes of these predictions are displayed in Table 1.

Table1– BackPressuresofvariousmufflerproposalsfromanalyticalmethodsofcalculations

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Sr.No.	Muffler Configuration	Back Pressure (mbar) calculated Target-250 mbar
1	Baseline	242.2
2	Iteration1	235.2
3	Iteration2	229.1
4	Iteration3	374.1
5	Iteration4	286.5

The back pressure of the previously given ideas was projected using analytical calculation methods, and the results are shown in table 1. During iterations 3 and 4, BP's proposed mufflers exceed the desired value. Based on the correlation factor between expected and measured blood pressure (BP), it was decided that real measurements should be pursued.

5. EXPERIMENTAL VALIDATION

The schematic flow diagram and experimental configuration utilized to determine TL are illustrated in figures 7 and 8, respectively. At one end of the experimental configuration are a speaker and a suppressor that are connected. A noise generator is utilized by the speaker to agitate the silencer cavity. In the silencer's upstream and downstream channels, two microphones were installed. The acoustic transfer functions between the two instruments were obtained through the implementation of a multichannel data capture system. The four pole parameters were obtained through further processing of the transfer functions in order to ascertain the TL of the silencer.

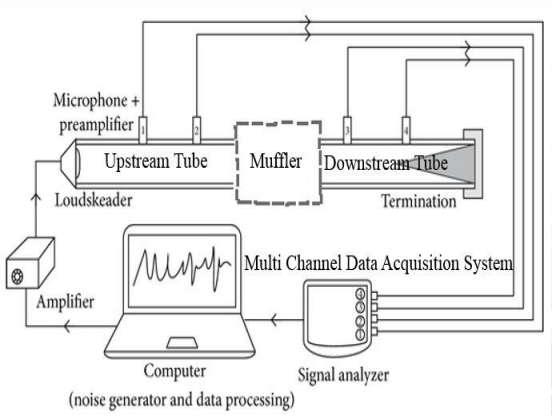


Fig.7SchematicoftheExperimental Set-upfor measuringTL

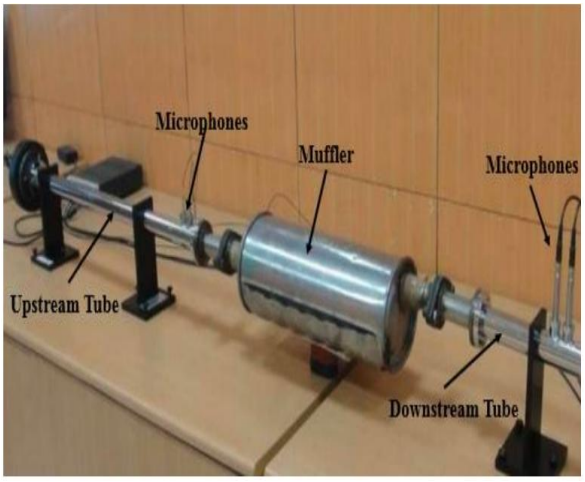


Fig.8ExperimentalSet-upfor TLmeasurement

Figure 9 shows the outcomes of the observed and computed TL for iteration 4. These TL values hold true over a wide variety of frequencies.

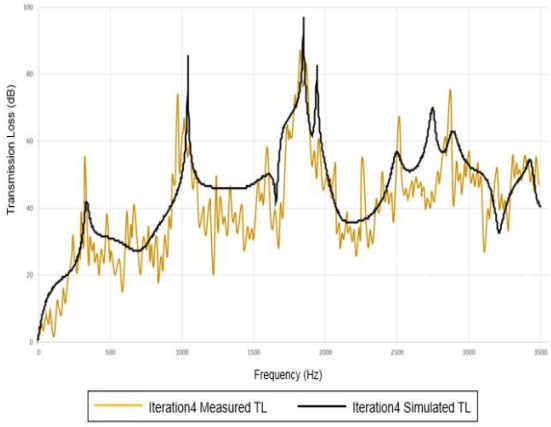


Fig.9ComparisonofsimulatedVsmeasuredTLofiteration4muffler

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The results are displayed in Figure 10, which compares the measured TL of the baseline muffler with that of the iteration 4 muffler.The baseline muffler also agrees with this.

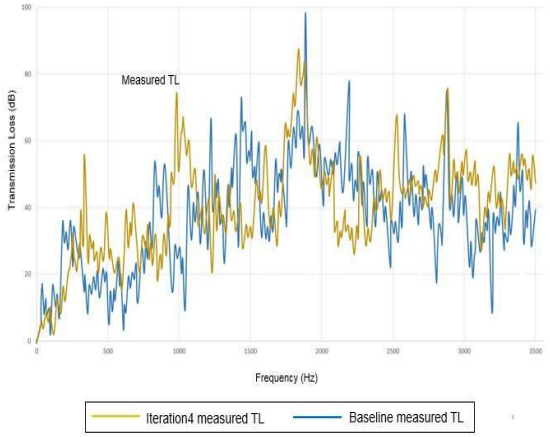


Fig.10Comparisonofmeasured TLofbaselineanditeration4muffler

Sr.No.	Muffler Configuration	Back Pressure (mbar) calculated Targte-250 mbar	Measured BP mbar
1	Baseline	242.2	299.0
5	Iteration4	286.5	258.0

Table 2-Comparision ofBPpredicted&measured

All three parameters (measured BP, simulated TL, and baseline muffler) fall within the acceptable range. The proposed muffler reduced both volume and weight, as indicated in table 3.

Sr.No.	Item	Units	Baseline Muffler	Reduced Size Muffler	D
1	Length	mm	524	450	
2	Volume	Litres	14	9	
3	Weight	kg	13.8	11	
4	Back Pressure calculated	mbar	299	258	

Table 3 –Size, volume andweightcomparisonsofbassline&propose dmuffler.

Therefore, this procedure results in a decrease in muffler size by 5 liters and a reduction in weight by 2.8 kg, while maintaining the NVH performance of the car.

6. CONCLUSIONS

Auto OEMs and component manufacturers strive to reduce the size, weight, and cost of the exhaust system without compromising vehicle performance metrics such as NVH, backpressure, and power. One approach is to assess the acoustic performance of the muffler through the utilization of Transmission Loss (TL). The current investigation determined that a 2.8 kg reduction in muffler weight and a 5 liter capacity reduction in muffler capacity had no adverse effect on the vehicle's initial performance. Further investigation is required to achieve complete optimization; however, the existing progress in muffler noise optimization, which relies on transmission loss-induced attenuation behavior, is exceedingly favorable.

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