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Muffler size minimization, using attenuation behaviour by acoustic simulation

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ABSTRACT

Engine noise coming from an automobile is a serious problem for the environment. The engine noise consists of combustion noise, mechanical noise & the noise from intake & exhaust system. Exhaust noise is the major noise which contributes to the overall engine noise. To control the exhaust noise, muffler of complex design is used. Designing a muffler is a challenging task faced by many, over the last few decades.

The major challenges faced by todays passenger car industry is getting the weight & cost reduction, without affecting the overall acoustic performance of the car. One of the objective of this study is to reduce the muffler size by using attenuation behavior, though acoustic simulation. The muffler attenuation characteristics are studied through the TL (Transmission Loss)& IL (Insertion Loss) .TL being the property of muffler, is being used widely for studying acoustic performance.

In the present dissertation work, base muffler is studied for TL & further design iterations are done to have a new muffler internals, which meet the baseline performance of the muffler. This is done by measuring the TL of baseline &modified muffler. Then comparison of the performance is made. The BP (back pressure) predictions are done by analytical methods of calculations for each iteration and ensured within the specified limit.The final confirmation of BP is done by measuring actual BP.

In conclusion, this benchmark study also can be used for optimization of muffler of current cars & can be even used during current design phases to reduce the design cycle times.

Keywords— **Acoustics, Attenuation, Decibel, Insertion Loss, Muffler, NVH, SPL (sound pressure level), Transmission Loss.**

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I. INTRODUCTION

Influence of automobile emission and noise, on environment, has become increasingly serious problem in recent years. The predominant component of automobile emission and noise is the exhaust system. Engine noise sources are combustion noise, mechanical noise & noise radiated from intake & exhaust. The exhaust noise is controlled through mufflers. Analysis of complex mufflers has been a great challenge & has become an active area of research [4]. There are two main categories, which are used to study this problem in the design of suitable muffler: The Transmission Loss (TL) and the Insertion Loss (IL).TL is the ratio of incident sound power to the output sound power, when end pipe is an anequaic termination.IL is the difference in sound power with & without the muffler, measured at a certain point near exhaust.TL is the property of muffler & therefore used widely for predicting the attenuation performance.

The current challenges in the passenger cars are, minimizing weights and costs, without compromising on the acoustic performance of the car. The minimization of weight and there by cost, is possible, only if the size of the muffler is reduced. The minimization of muffler size is done by studying the attenuation behavior through Transmission Loss (TL) of the muffler. This attenuation behavior of the muffler is analyzed though the acoustic simulation software's like AVL Boost, GT Power, Ricardo Wave etc.Genearlly 1D simulation software is used for analyzing the Transmission Loss (TL). The major challenges in achieving the minimization of muffler size are packaging

constraints in the cars due to space availability and keeping back pressure and attenuation targets within the same acceptable limits.
The present work is related to reducing the muffler size, by keeping the acoustic performance intact, by comparing TL of current & proposed optimized muffler.

II. LITEARTURE REVIEW

There has been a great deal of research and development in the area of predicting muffler performance [4]. Muffler performance from a designer's standpoint is characterized by either the Transmission Loss (TL) or Insertion Loss (IL) of the muffler. The benefit of TL is that it is a parameter of the muffler alone and the source or termination properties are not needed. Because of the simplifications, the TL is the most common parameter for muffler performance [5].The commercial automotive mufflers are generally of a complicated shape with multiple connected parts and complex acoustic elements

III.MUFFLERDESIGN THEORY AND ACOUSTIC PROPERTIES

The purpose of the automotive exhaust muffler is to reduce the noise of the engine. Noise is defined as the unwanted sound [1]. Sound is a pressure wave formed by pulsation of alternating, high pressure & low pressure air. When exhaust valve of engine opens, high pressure gases are poured into the exhaust system. This creates high pressure waves. These high pressure pulses are the sound we hear. As the engine rpm increases, pressure fluctuations increase & the emitted sound is of high frequency.

The automotive muffler has to allow passage of the exhaust gases while restricting the transmissions of the sound. Mufflers used to attenuate the undesired noise can be of three types- reactive, dissipative and combination of reactive & dissipative.

The reactive or reflective mufflers use the phenomenon of destructive interference to reduce noise. A reactive muffler, as shown in Figure 1, generally consists of a series of resonating and expansion chambers that are designed to reduce the sound pressure level at certain frequencies. The inlet and outlet tubes are generally offset and have perforations that allow sound pulses to scatter out in numerous directions inside a chamber resulting in destructive interference.[2]

Inlet

Outlet

An absorptive or dissipative muffler, as shown in Figure 2, uses absorption to reduce sound energy. Sound waves are reduced as their energy is converted into heat in the absorptive material.[1,2] A typical absorptive muffler consists of a straight, circular and perforated pipe that is encased in a larger steel housing. Between the perforated pipe and the casing is a layer of sound absorptive material that absorbs some of the pressure pulses.

Figure 2. Absorptive Muffler

Absorptive mufflers create less backpressure then reactive mufflers, however they do not reduce noise as well. Generally reactive mufflers use resonating chambers that target specific frequencies to control noise whereas an absorptive silencer reduces noise considerably over the entire spectrum and more so at higher frequencies.

It is good practice to design a muffler to work best in the frequency range where the engine has the highest sound energy. In practice the sound spectrum of an engine exhaust is continually changing, as it is dependent on the engine speed that is continually varying when the car is being driven. There is always more than one way to design a muffler for a specific application, however if the designed muffler is practical and achieves the required noise reduction and meets all functional requirements then the designer has succeeded.

There are several parameters which describe the acoustical performance of a muffler.[3] These include noise Reduction (NR), Insertion Loss (IL), Attenuation (ATT), and the Transmission Loss (TL). Noise Reduction is the sound pressure level difference across the muffler. It is an easily measurable parameter but difficult to calculate and a property which is not reliable for muffler design since it depends on the termination and the muffler. The Insertion loss is the sound pressure level difference at a point usually outside the system, without and with the muffler present. Insertion loss is not only dependent on the muffler but also on the source impedance and the radiation impedance. Because of this insertion loss is easy to measure and difficult to calculate, however insertion loss is the most relevant measure to describe the muffler performance. For TL,since it is difficult to realize a fully anechoic termination (at low frequencies) TL is difficult to measure but easy to calculate. Attenuation is the difference in the sound power incident and the transmitted through the muffler but the termination need not be anechoic.

The most common approach for measuring the transmission loss of a muffler is to determine the incident power by decomposition theory and the transmitted power by the plane wave approximation assuming an anechoic termination.[5] Unfortunately, it is difficult to construct a fully anechoic termination

III. Design Iterations through Noise Simulation

The objective of this study was to minimize the size of the muffler without affecting the acoustic performance of the car. In turn, get the weight and cost reduction of the car ,with constraints of packaging space availability and meeting engine back pressure targets, at the same time meeting NVH(Noise Vibration Harshness) targets of the car. Refer fig.3 for baseline and the required muffler.

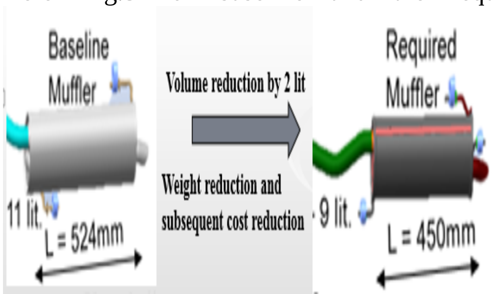


Fig.3Baseline and Required Muffler

The internal details and the 1d AVL boost model of the base line muffler with details of number of holes & perforations, diameters on pipes & baffle plates is as shown in fig4.

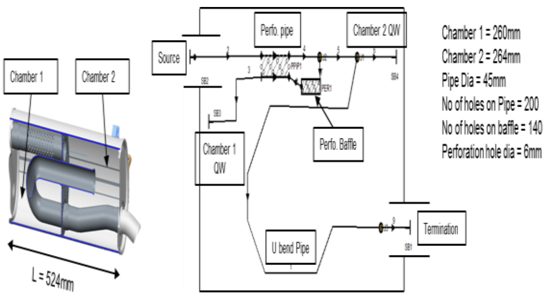


Fig.4 Internals &1d AVL model of Baseline muffler

The simulation of TL of baseline muffler is made through AVL boost and is as shown in fig.5

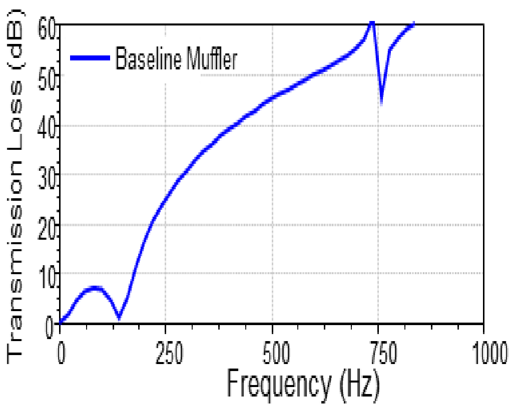


Fig.5 TL of baseline muffler

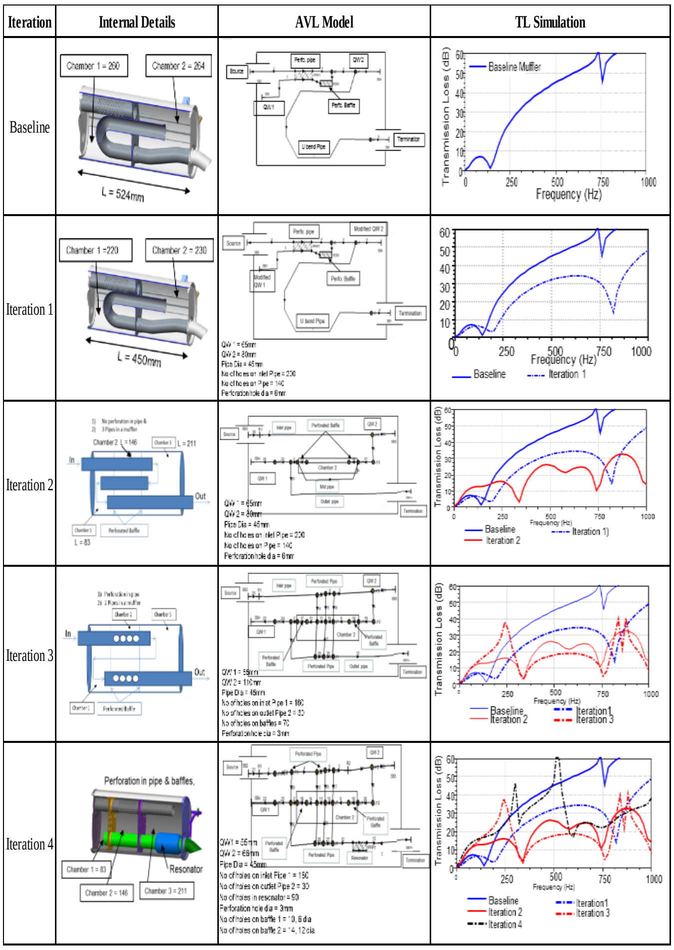
In order to meet the same attenuation performance as that of the baseline muffler, below design iterations as shown in table1 were made through the AVL Boost simulation.

Table 1 –Muffler Configurations

Sr.No.	Muffler Configuration	Remarks
1	Baseline	Current Design(2 chamber with U tube)
2	Iteration1	Current internals with length reduced from 524 to 450 mm
3	Iteration2	New internals with 3 chambers (2 pipes)
4	Iteration3	New internals with 3 chambers(3 pipes)
5	Iteration4	New internals with 3 chambers (2 pipes & resonator)

The TL noise simulation results of 4 iterations and the comparison with baseline muffler is shown in below table2.

Table2 – Muffler configurations and simulation results comparisons with baseline muffler



The back pressure prediction for the above iterations was done based on analytical calculations methods and the comparisons are shown in the table 3.

Table 3 – Back Pressures of various muffler proposals from analytical methods of calculations

Sr.No.	Muffler Configuration	Back Pressure (mbar) calculated Targte-250 mbar
1	Baseline	235
2	Iteration1	229
3	Iteration2	259
4	Iteration3	260
5	Iteration4	261

Iteration 1 was chosen by just reducing the length of the baseline muffler. As can be seen from the simulation results, the iteration 1 results not matching the target TL of bassline muffler. Therefore 2nd iteration was made with new internals of the muffler. But simulation results of TL, did not match with the bassline muffler TL.Therefore 3rd iteration was made modified new internals. However, simulation results of this proposals also not match with baseline muffler. Therefore went for the 4th iteration of completely new internals. The TL simulation results of this proposals match with the baseline muffler. Therefore this design was taken forward for the actual manufacture of prototype.

Back pressure prediction of the above proposals was made through analytical calculations methods and are as shown in table 3. For iteration 2, 3 and 4 proposal mufflers, BP is more than targeted value. Considering correlation factor between predicted and actual measured BP, it was decided to go ahead with actual measurements.

V.EXPERIMENTAL VALIDATION

The schematic flow diagram and the experimental set up for measuring TL is as shown in the fig.6 and fig 7. [3,5]The experimental setup consists of a speaker connected to the silencer at one end. The speaker excites the silencer cavity using a random noise generator. Two microphones were placed at the upstream and downstream tubes of the silencer. A multi-channel data acquisition system was used to acquire the acoustic transfer functions between the two microphones. The transfer functions were further processed to obtain the four pole parameters, which leads to the TL of silencer [5].

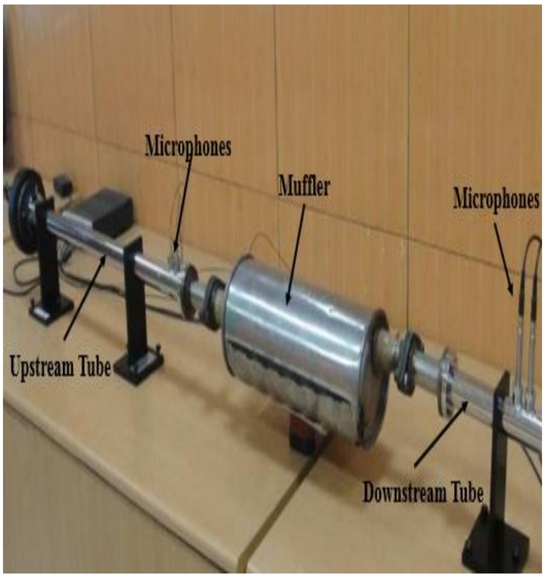


Fig.7 Experimental Set-up for TL measurement

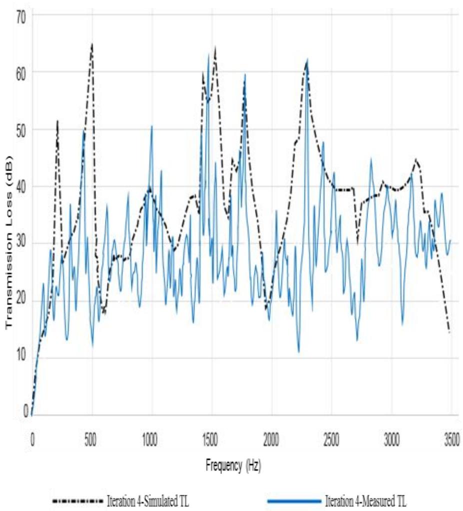


Fig.8Comparison of simulated Vs measured TL of iteration4 muffler

Finally the measured TL of baseline muffler and iteration4 muffler is compared and shown in fig 9.This is also in line with baseline muffler.

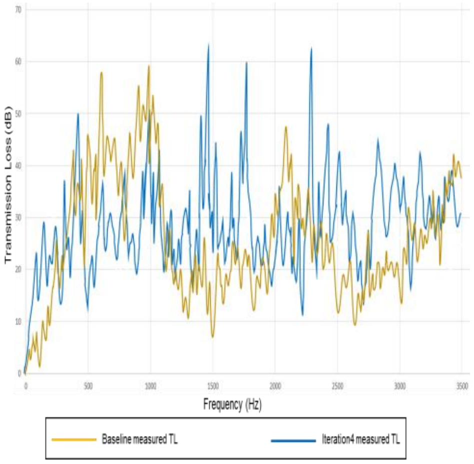


Fig.9 Comparison of measured TL of baseline and iteration4 muffler

Back pressure confirmation is done by actually measuring the BP on engine test bed. The results are shown in table 4 below.

Table 4-Comparision of BP predicted & measured

Muffler Configuration	Back Pressure (mbar) calculated Targte-250 mbar	Measured BP mbar
Baseline	235	229
Iteration4	261	235

The measured BP is within the specified limit and the measured TL & simulated TL is in line with the baseline muffler. The volume and weight reduction achieved with the proposed muffler is as shown in the table5.

Table 5 – Size, volume and weightcomparisons of bassline& proposed muffler

Sr.No.	Item	Units	Baseline Muffler	Reduced Size Muffler	Difference	Remarks
1	Length	mm	524	450	74	Length reduction
	Major Axis	mm	213	213	0	
	Minor Axis	mm	142	142	0	
2	Volume	Litres	11	9	2	Volume reduction
3	Weight	kg	10.6	9.8	0.8	Weight reduction of 800 m

Thus with this process, muffler size is reduced by 2 liters along with weight reduction of 0.8 kg without affecting the NVH performance of the car.

VI.CONCLUSION

Muffler designed with iteration 4 was the best optimized design, which meet the acoustic as well as backpressure target requirements, after reducing the size of the muffler from 11 litres to 9 litres.

This study presents a benchmark methodology, for reducing the muffler size, by using attenuation behaviour of muffler, through acoustic simulation of TL. It takes into account the constraints of noise & BP, which form basis for the design of muffler.

This methodology helps the manufacturer as well OEMs to reduce the size, weight and cost of the exhaust system.

VII.FUTURE SCOPE

The same methodology can be used for reducing the design cycle time of the muffler designs of any new car.

The method can be used for optimization of current designs of mufflers on the car to get the weight and cost reduction benefits.

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