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Design and Optimization of Muffler for Manufacturing

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ABSTRACT-The main purpose of a muffler in an automobile is to reduce the engine noise. An automotive muffler is designed and modified to achieve attenuation and back pressure targets. Attenuation and back pressure characteristic of base muffler is altered by changing its internal configuration. The target value was set at the time of conceptual stage and to obtain these targets, the muffler internal construction is modified. The targeted value is a compromise between the transmission loss and the backpressure. CAE tools are used for simulating the environment to achieve targeted TL(Transmission Loss**)** and back pressure. Experimental test have been conducted to check and correlate with CAE results in order to evaluate the effect of muffler internal construction on both TL and backpressure.

Keywords: Transmission Loss, Insertion Loss, Sound Pressure Level, Back Pressure

I.INTRODUCTION

Noise pollution created by engines [5] becomes a vital concern when used in residential areas or areas where noise creates hazard. Generally, noise level of more than 80 dB is injurious for human being. The main sources of noise in an engine are the exhaust noise and the noise produced due to friction of various parts of the engine. Internal combustion engines [4] are typically equipped with an exhaust muffler to suppress the acoustic pulse generated by the combustion process. A high intensity pressure wave generated by combustion in the engine cylinder propagates along the exhaust pipe and radiates from the exhaust pipe termination. The purpose of an automotive muffler is to reduce the engine noise emission. If vehicles did not have a muffler, there would be an unbearable amount of engine exhaust noise in the environment. Noise is defined as unwanted sound. Sound is a pressure wave formed from pulses of alternating low and high pressure air. In an automotive engine, pressure waves are generated when the exhaust valve repeatedly opens and lets high pressure gas into the exhaust system. These pressure pulses are defined as sound. As the engine speed increases, the pressure fluctuation also got increased and this leads to a higher frequency.

All noise emitted by the automobile [4] does not come from the exhaust system. Other contributors to vehicle noise emission include intake noise, mechanical noise and vibration induced noise from the engine body and transmission. The automotive muffler has to be able to allow the passage of exhaust gases whilst restricting the transmission of sound. The exhaust system contributes 32% of the total noise emitted from the vehicle.

A.TypesOf Muffler

Muffler is one of the major exhaust system components and it is broadly classified into two types based upon its operating mechanism.Reactive muffler

- Absorptive muffler

B.Reactive Muffler

The reactive or reflective muffler [4] uses the phenomenon of destructive interference to reduce the noise. This means that they are designed so that the sound Waves produced by an engine partially cancel themselves out in the muffler. For complete destructive interference to occur, a reflected pressure wave of equal amplitude and 180 degree out of phase needs to collide with the transmitted pressure wave. Reflections occur when there is a change in geometry or an area discontinuity.

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C.Absorptive Muffler

Absorptive silencers [4] contain either fibrous or porous material, and depending upon their absorptive properties they reduce the noise levels. Sound energy is reduced as their energy is converted into heat in their absorptive material. It is based on the use of flow resistive materials, again normally in the form of porous acoustic linings.

In hybrid type [3], Sound is attenuated by reflection and cancellation as well as absorption and in active noise control method; they used the noise cancellation method to attenuate the sound.

D.Design Targets

During the design process of the muffler the design targets need to be achieved. Some of the design targets are as follows

- Transmission loss
- Insertion loss
- Tail pipe noise
- Backpressure

E.Transmission Loss

Transmission loss is a key quantification of the effectiveness of muffler for engineering application. Transmission loss indicates how much sound energy is prevented from travelling through a muffler. Transmission loss is the difference in the sound power level between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic. The transmission loss is a property of the muffler only.Calculation methods able to predict the transmission loss and the back pressure for a muffler with complex interior perforated ducts and baffles. Possible calculation methods are the transfer matrix method, finite elements method, boundary element method or computational fluid dynamics method. Commercial 1D/3D codes like WAVE, Star CCM+ and LMS Virtual lab can help to predict the transmission loss and back pressure of the muffler.

F.Insertion Loss

The insertion loss is the sound pressure level difference at a point, usually outside the system, without and with the muffler present. Though the insertion loss is very useful to industry, it is not so easy to calculate since it depends not only on the muffler geometry itself but also on the source impedance and the radiation impedance.

G.Back Pressure

Back pressure caused by the exhaust system muffler of an automotive four-stroke engine has a negative effect on engine efficiency resulting in a decrease of power output that must be compensated by increasing fuel consumption.

H.Noise Target

The noise target for different vehicles is as mentioned in figure 1. The allowable noise target in India for passenger cars< than 4tonne is 77 dB.

Type of Vehicle	Allowed Noise Level (dB)			
	INDIA	EUROPE	JAPAN	AUSTRALIA
2 - Wheeler Displacement up to 80 cc	75	72	75	77-81
2 – Wheeler Displacement more than 80 cc to 175 cc	77	74	76	77
2 – Wheeler displacement more than 175 cc	80	78	79	81
3 – Wheeler Displacement up to 175 cc	77	N.A	N.A	77
3 – wheeler Displacement more than 175 cc	80	N.A	N.A	N.A
Passenger or commercial vehicle Gross vehicle weight up to 4 ton	77	74 / 75	83	83
Gross vehicle weight more than 4 tonne to 12 ton	80	78	83	83
Gross vehicle weight more than 12 ton	82	80	83	86

Figure 1.Noise Regulation.

II.DESIGN METHODOLOGY

The Different criterions to be considered for muffler designs are acoustical, aero dynamical, mechanical, geometrical and economical. Where aero dynamical criterion specifies the maximum acceptable back pressure through the muffler for a given temperature and mass flow rate, mechanical criterion specifies the material from which the muffler is fabricated so that it is durable and require less maintained, geometrical criterion specifies the maximum allowable value and restriction on shape and economical criterion is vital in the market place.

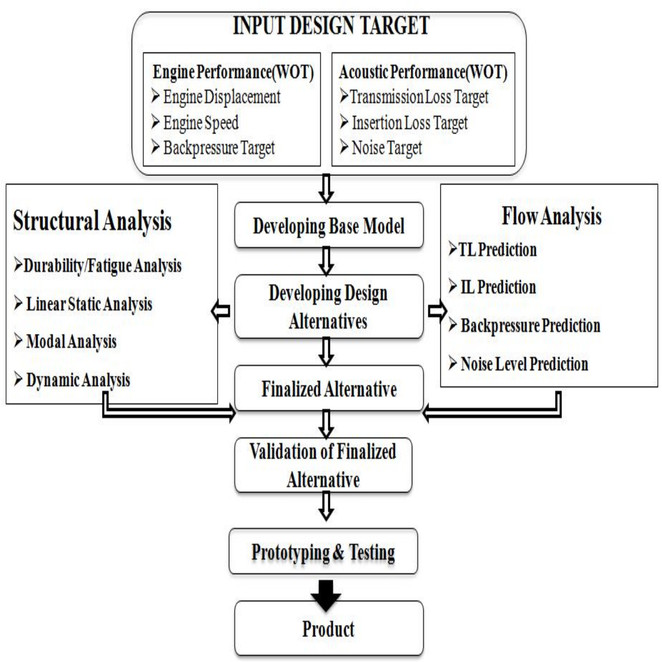

Figure 2.Muffler Design Methodology.

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A.Muffler Internals Design

Muffler internalconstructions like number of baffles, pipe diameter, length and, and number of perforations amount of absorption materials are decided to meet the back pressure and acoustics targets. The muffler internal elements design criteria with each of its pros and cons are shown in figure 3.

S.No	ELEMENTS	PROS	CONS	REMARKS
1.	Perforated baffle plate	It reduces the velocity of the exhaust gas by obstructing the flow and attenuates noise.	Increase in backpressure level.	Backpressure can be minimized by varying hole diameter & pattern.
2	Non – Perforated baffle plate	It attenuates the sound by destructive interference by obstructing the flow.	Increase in backpressure level.	Noise attenuation is increased using acoustical structures on the baffle plate.
3	Perforated Tube	The exhaust gas expands through the perforations and the velocity of the flow is decreased, which in turn reduces the noise level	Backpressure is increased based on the expansion rate.	The noise reduction can be achieved by varying the hole diameter & distribution pattern of the holes.
4	Non – Perforated tubes	It directs the flow the gas through the muffler. The noise attenuation increases with the increase in the tube diameter.	Small diameter tube increases the backpressure.	Diameter of the tube is designed based on the engine displacement.
5	Shell or Casing	It provides the expansion of the gas and it holds components in constraints and prevent them from vibrating.	Thickness should be optimum, that it wont crack or increase the weight of the system	The volume plays an important role in noise reduction.
6	Absorption Material	The attenuation of noise is done by converting sound energy into heat energy.	It should withstand varying temperature . It slightly affects backpressure level.	The material should be thermally stable and withstand high temperature.

Figure 3. Design Criteria

III.ENGINE SPECIFICATIONS

The given engine is having a displacement of 900cc with a speed of 6000 rpm. The muffler is designed mainly to reduce the sound at engine firing frequency of 70 Hz. The engine is having 3 cylinders with an exhaust temperature of 750^{o} C. The designed muffler has a length of 430mm with 2 baffle plates, 3 tubes, 1.2 mm thick, and it is having an elliptical shape with a major diameter of 206mm and Minor diameter of 136mm. The three models have been designed to achieve the target level.

A. Absorptive Material

Glass wool has a good sound absorption property. It absorbs the sound and converts it into heat energy and it can with stand high temperature of 800 °C continuously, it will be very effective at higher frequencies and having a good corrosion resistivity. The absorption coefficient of glass wool is shown in the graph below

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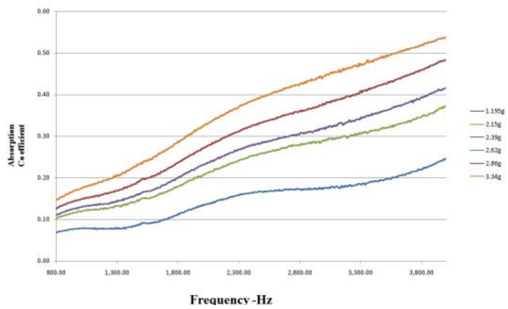

Figure 4.Absorption Coefficient of glass wool.

B.Muffler Material

In metallurgy[2], stainless steel also known as inox steel is defined as a steel alloy with a minimum of 10.5 or 11% chromium content by mass. Stainless steel does not stain, corrode, or rust as easily as ordinary steel, but it is not stain-proof. Stainless steel is used where both the properties of steel and resistance to corrosion are required. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure.

C.Properties

High oxidation-resistance in air at ambient temperature is normally achieved with additions of a minimum of 13% (by weight) chromium, and up to 26% is used for harsh environments. The chromium forms a passivation layer of chromium (III) oxide (Cr_2O_3) when exposed to oxygen. The layer is too thin to be visible, and the metal remains lustrous. The layer is impervious to water and air, protecting the metal beneath. Also, this layer quickly reforms when the surface is scratched. This phenomenon is called passivation and is seen in other metals, such as aluminum and titanium. Corrosion-resistance can be adversely affected if the component is used in a non-oxygenated environment.

D.Features

It is having a higher corrosion resistance, staining resistance, lower maintenance and low material cost.

E.Base Model

The base model is designed with perforations of 208 and 45 in each tube and baffles respectively and it is having 220g of glass wool as an absorptive material. The backpressure and transmission loss can be identified by using CFD and WAVE Software. The backpressure is identified as 105mbar by giving the adiapatic condition to the inner surface, heat transfer coefficient to the outer and side wall with a mass flow rate of 220 Kg/hr. The average transmission loss is identified as 19.0 dB by giving the speaker amplitude as 0.1 m/sec, frequency range of 10 – 4 KHz, distance between the microphone as 40mm, distance between the microphone end to muffler as 120mm, constant velocity magnitude as -1 m/sec, with ambient pressure and temperature as air as a standard medium.

IV.TRANSMISSION LOSS RESULTS FOR BASE MODEL

Then the experimental setup has been done to identify the experimental transmission loss value and also for correlation with the same condition as in WAVE.

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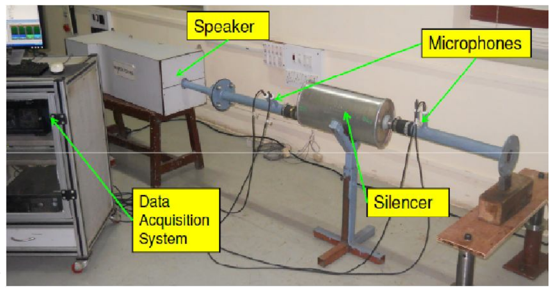

Figure 5.Experimental setup for base model.

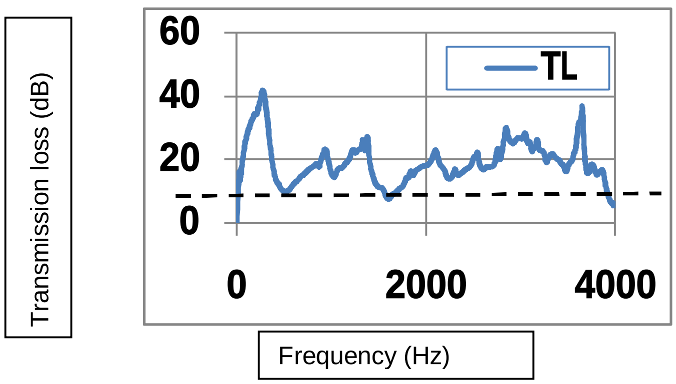

Figure 6. Base model experimental result

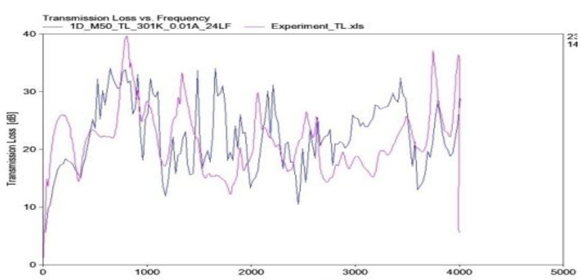

Figure 7. Correlated results for base model

The experimental transmission loss for the base model does not meet our target level. so the option has been shifted to variant 1 by increasing the density of glasswool as 300g and removing the perforations in one tube and found the backpressure value as 54 mbar which is comparatively lesser than the previous one . Due to the cost factor, it is not selected as the optimized model.Then the variant 2 has been designed by increasing the perforations as 144 in each baffle plate and 676 holes in tubes by keeping the glasswool density as 220g. Then the backpressure can be found as 55 mbar and transmission loss by WAVE as 21.3 dB which meets the target level. Then the experimental TL was found by using the same setup with same conditions and found the value as 21.7 dB which is comparatively higher.

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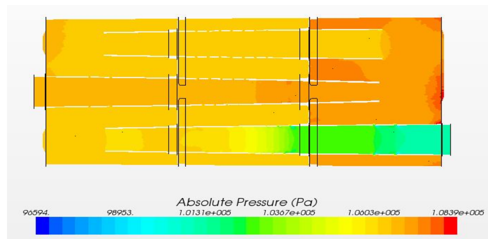

Figure 8.Cfd post processing results for variant2

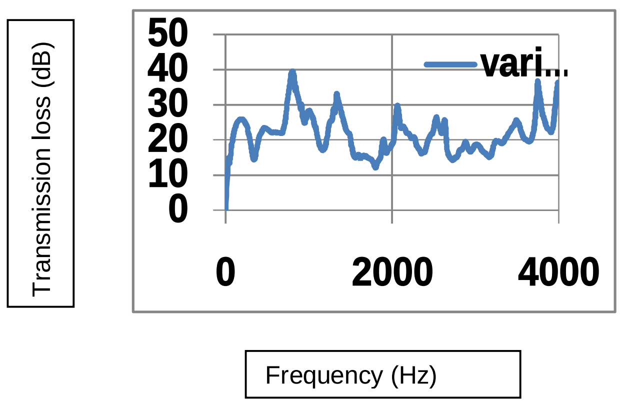

Figure 9 Experimental results for variant 2

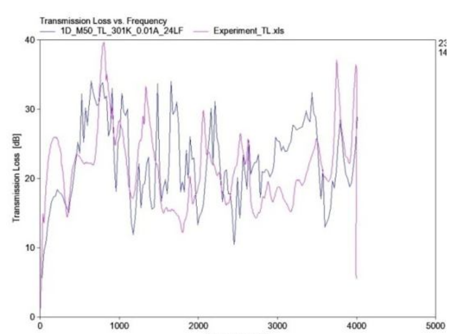

Figure 10. Correlated results for variant 2

Variant 2 is then simulated in WAVE for tail pipenoise andInsertion loss analysis.

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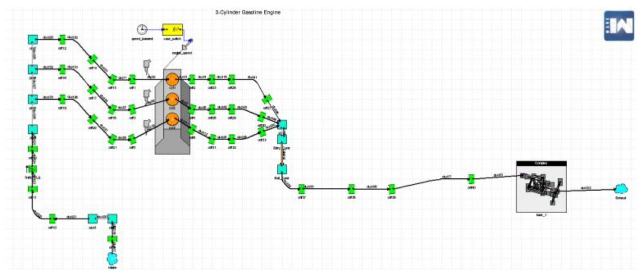

Figure11 WAVE 3-cylinder engine model

A.Insertion Loss Measurement

Insertion loss is defined as the ratio between the acoustic power radiated without the muffler fitted and with the muffler fitted, expressed in db as function of frequency.

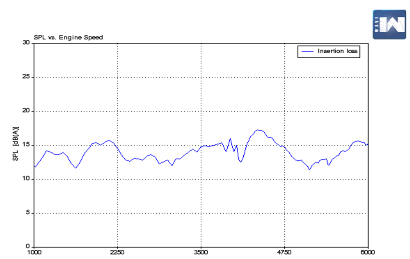

Figure12 Insertion loss graph

It is observed that insertion loss at 1000 rpm is 12 dBand for 6000 rpm it is 15 dB A. Adequate insertion loss is found in variant 2.

B. Tail Pipe Noise Measurement

This noise is measured by using microphone from 500mm distance at 45° from the tail pipe end . The engine is operated at full load RPM.

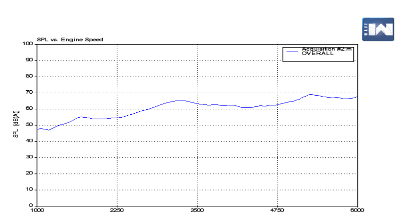

FIGURE13**:** Result obtained from WAVE

In the tail pipe measurement it is observed that 50 dB(A) at 1000 rpm and 70 dB(A) at 6000rpm which is within the target.

V.CONCLUSION

It is concluded that variant 2 was selected as an optimized model and the simulation results are verified with experimental results and also the tail pipe noise and back pressure optimization can be achieved by increasing the number of perforations without increasing the density of the absorption material.

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