NVH Characterisation of BS-III and BS-IV Exhaust System

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Abstract

Function of an exhaust system is to muffle noise from engine exhaust and control emissions while maintaining back-pressure on engine as low as possible. This makes design of muffler more complex and challenging for muffler design engineer. With the implementation of BS-IV norms, designer had to redesign the muffler to include technologies such as Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) without disturbing the noise attenuation properties of muffler i.e. Transmission Loss (TL) and Insertion Loss (IL). For this reason BS-IV SCR muffler was developed over BS-III conventional muffler and hence this work has been carried out to experimentally evaluate the noise attenuation capacity of these mufflers i.e. TL and IL and to establish comparison in between them.

Transmission Loss is the difference in the sound power level between the incident wave and the transmitted wave exiting the muffler when the muffler termination is anechoic. With the help of impedance tube, sound source, microphones and DAQ, TL of these two mufflers were measured using Two Load Method. Insertion loss is the difference between sound pressure levels measured before and after a muffler has been inserted between the source and the measurement point and represents the real noise reduction from the customer's point of view. Measurement of Insertion Loss was carried out as per the standard of ISO 5130. Finally a detail comparison of noise attenuation properties of BS-III and BS-IV exhaust systems is made.

Key Words : Muffler, Insertion Loss, Transmission Loss, NVH

1. INTRODUCTION

Modern vehicle development requires Noise, Vibration, and Harshness (NVH) refinement to obtain the proper level of customer satisfaction and acceptance. The principle sources of noise in an automobile are engine, intake, fan, exhaust etc. Out of these exhaust noise is predominant. The control of Noise from the exhaust system depends on the design of the muffler, the layout of the exhaust system, the piping etc. but specific focus is always towards the design of the muffler. Design of mufflers is a complex function that affects the noise characteristics and the fuel efficiency of the vehicle. So, a good design of muffler should give the best noise reduction and offer optimum backpressure for the engine.

One of the functions of an exhaust system is to control the emissions that are caused by vehicle engine. Bharat Stage emission standards are instituted by the Government of India to regulate the output of air pollutants from internal combustion engine equipment. In 2010, Bharat stage – III (BSIII) was implemented Nationwide and Bharat stage – IV (BS-IV) was implemented in Delhi and 13 major cities. This was another challenge for designers to develop an exhaust system that would meet these norms. For this purpose technologies such as Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR) are used.

In this work an attempt has been made to characterize two different exhaust systems i.e. BS-III conventional exhaust system and BS-IV SCR exhaust system in terms of NVH parameters. Transmission Loss (TL) and Insertion Loss of mufflers were measured experimentally to check noise performance.

2. EXHAUST SYSTEMS CONSIDERED IN THIS WORK

The exhaust system for any particular application should satisfy several often conflicting demands simultaneously. These include:

- The acoustic criterion, which specifies the minimum noise reduction, required from the muffler as a function of frequency.
- The gas dynamics criterion, which specifies the maximum acceptable average pressure drop through the muffler at a given temperature and mass flow.
- The geometrical criterion, which specifies the maximum allowable volume and restrictions on shape.
- The mechanical criterion, such as low maintenance and high durability, which in turn dictates the materials used.
- Emissions criterion – which technologies to use to satisfy the emission norms in place.

Keeping the above criteria in mind, two different exhaust systems are considered in this work. These are classified in Table 1:

Table 1: Classification of Exhaust System

Classification Based on :	**BS-III Conventional Exhaust system**	**BS-IV SCR Exhaust System**
		
Muffler Layout/Routing	Side Exhaust	Side Exhaust
Muffler shape	Oblong	Elliptical
Muffler I/O position	End In/End Out	End In/End Out
After-treatment Technology	Conventional	With SCR

3. TRANSMISSION LOSS

There are several parameters that describe the acoustic performance of the muffler. These include the noise reduction (NR), the insertion loss (IL), and the transmission loss (TL). The NR is the sound pressure level difference across the muffler. Though NR can be easily measured, it is not useful for muffler design. The IL is the sound pressure level difference at a point, usually outside the system, with out and with the muffler present. TL is the difference in the sound power level between the incident wave and the transmitted wave exiting the muffler when the muffler termination is anechoic

$$TL = 10\log_{10}\frac{W_i}{W_t}$$

where Wi is the incident sound power and Wt is the transmitted sound power. The TL is the property of the muffler only and is the parameter on which the performance of the muffler is evaluated.

3.1. Measuring Techniques of transmission Loss

There are five methods of measuring the transmission loss, namely

1. Plain Wave method 2. Two room method 3. Decomposition method 4 Two source method 5. Two Load Method

Two Load Method has been used in this work. The experimental evaluation of transmission loss is carried out in the absence of the flow for two different mufflers. When an acoustic signal is incident on a muffler, a part of it is reflected back because of area discontinuities. At the inlet of the muffler the signal consist of both forward and backward travelling components. Transmission loss can be experimentally determined by measuring the auto spectral values of the wave incident on the muffler and the wave transmitted into an anechoic termination. The incident wave cannot be isolated directly from the reflected wave. However, the transmitted signal can be measured directly as the end condition is anechoic. The decomposition of the incident wave and hence transmission loss measurements is made by four-microphone method. Figure 1. show the flow diagram of experimental setup to measure transmission loss of muffler.

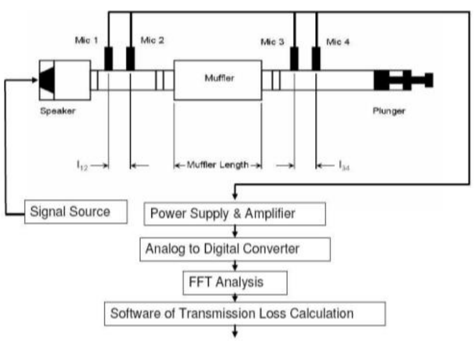

Figure 1. Flow diagram of experimental set up to measure TL of mufflers

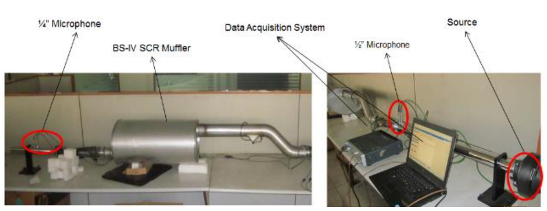

Figure 2. Transmission Loss Test Setup

Figure 2. represents Transmission Loss Test setup. Signals from microphones, which are mounted on impedance tube are acquired by DAQ and this acquired data is than analyzed for the desired range of frequency. The data was processed using *LMS Test.Lab 12A \ Test.Lab Acoustic*. The below Table 2. shows the TL obtained in dB for respective frequency.

Table 2: Transmission Loss in dB

Frequency (Hz)	TL in dB	
	BS-III Conventional muffler	BS-IV SCR muffler
0	-3.40282E+38	-3.40282E+38
100	21.99304581	12.60646887
200	14.60243208	21.47918297
300	30.9146073	17.75763704
400	24.8067925	22.10365953
500	44.03648811	30.33777078
600	38.1730982	28.44094352
700	41.03740138	23.00817114
800	37.33927292	42.03038446
900	41.03950644	17.19672511
1000	46.73523	21.73289461
1500	44.41988037	23.08183472
2000	24.72815589	26.2632552

4. INSERTION LOSS

Insertion loss is the difference between sound pressure levels measured before and after a muffler has been inserted between the source and the measurement point and represents the real noise reduction from the customer's point of view. There are a number of different definitions for insertion loss measurements, but one shown in figure 3. being the most common. In this work definition (a) i.e LIL = LP2 -LP1 is used calculate IL, i.e keeping the sound Level Meter (SLM) at same receiving point, where ‘LP1’ & ‘LP2’ are Sound Pressure Level measured with and without muffler, ‘LIL’ is difference in sound Pressure Level ie. Insertion Loss. Some authors have recently moved to using the term insertion impact as opposed to insertion loss as this more accurately describes the effect of introducing a new element into an acoustic system that can result in both an increase and a decrease in radiated sound.

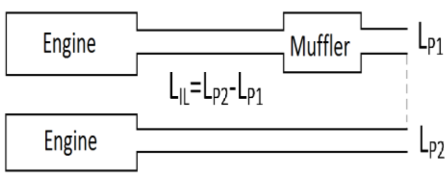

Figure 3. Insertion Loss Definition

4.1. Measurement of Insertion loss

Measurement of insertion loss was carried out as per the standard of ISO 5130 on an engine with Rated Power of 123Kw @ 2500 rpm and Maximum torque at 550Nm @ 1200 – 1800rpm. The measurements were taken for three different conditions i.e. Idling, Maximum Power and at Fly-up condition. For each conditions first un-muffled (without muffler just with pipe) sound pressure level was measured and then by fitting BS-III conventional muffler and BS-IV SCR & EGR Mufflers. The measured values are shown in Table 3.

Table 3: Measured Insertion Loss Values

Measurement Conditions			BS-III conventional muffler	BS-IV SCR Muffler
Idling (600 rpm)	Un-muffled dB (A)		89.1	89.1
	Muffled dB (A)		76.8	76.8
	Insertion loss dB (A)		**12.3**	**12.3**
Max.power (2500 rpm)	Unmuffled dB (A)		109.5	109.5
	Muffled dB (A)		89.4	89
	Insertion loss dB (A)		**20.1**	**20.5**
Fly-up (2750 rpm)	Unmuffled dB (A)		110.1	110.1
	Muffled dB (A)		90.8	90
	Insertion loss dB (A)		**19.3**	**20.1**

5. RESULTS AND DISSCUSION

The purpose of this work was to characterize two different exhaust systems w.r.t NVH parameters i.e. Transmission Loss and Insertion Loss and to study its effect on customer perceived performance such as noise attenuation. For this purpose two tests were performed.

5.1. Transmission Loss

Two Load Method was used to measure the transmission loss of mufflers using impedance tube over the frequency range of 0-2000 Hz. Since these devices are Reactive-Absorptive muffler, it provides broad-band noise control. Figure 4. shows the measured TL for three mufflers. The average TL values of BS-III Muffler is 47.50dB and for BS-IV Muffler is 34.94dB.

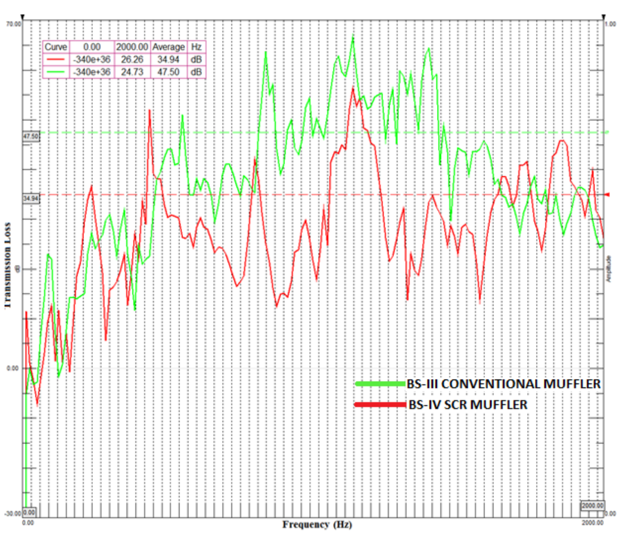

Figure 4. Insertion Loss Definition

Following are the observations:

i. The average Transmission Loss for BS-III conventional muffler is 47.50 Db and for BS-IV SCR muffler is 34.94 dB.

ii. Most of the peaks of TL are observed at engine firing frequency and its harmonics.

iii. Noise attenuation capacity of muffler should be increased in lower frequency range (0-500Hz).

iv. BS-III conventional muffler is for conventional 6-cylinder engine whereas BS-IV SCR Muffler is for Common Rail Injection System (CRS) 6-cylinder engine.

Exhaust noise produced by Conventional 6-cylinder engine is greater than CRS 6-cylinder engine. Hence Average TL of BS-III Conventional Muffler should be greater than BS-IV SCR Muffler. Hence obtained TL values satisfy the TL requirement of above muffler.

5.2. Insertion Loss

Insertion Loss measurement was done over a frequency range of 2000Hz. Figure 5. (a), (b) and (c) shows the measured noise level at idling, max. power and fly-up conditions respectively.

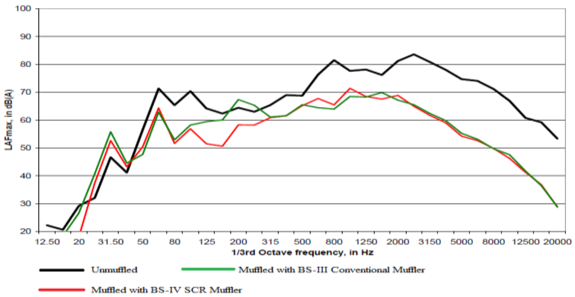

Figure 5.a. Exhaust spectrums for Idling condition

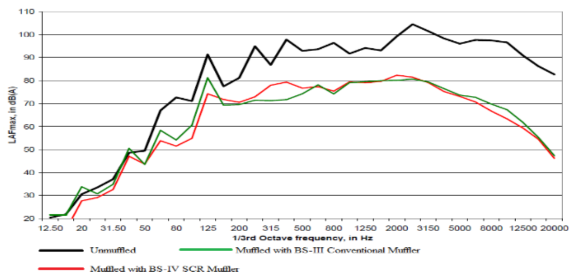

Figure5.b. Exhaust spectrums for Max. Power condition

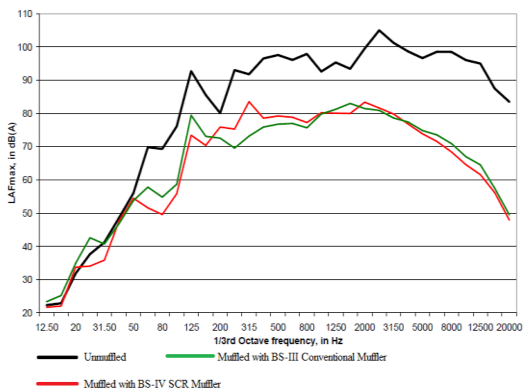

Figure 5.c. Exhaust spectrums for Fly-up condition

6. CONCLUSION

Experimental evaluation of Transmission loss and insertion loss was made for BS-III conventional muffler and BS-IV SCR Muffler. Although there is a difference in the design of these two mufflers, it has been observed buy the experimental results that they have adequate amount of Transmission Loss (although TL value is comparatively less in the lower frequency band -500 Hz) and Insertion Loss.

It is not necessary to have fixed TL value for muffler. It has to be based on the engine type and final noise attenuation requirement. Unnecessary system based TL improvement will increase the cost. Hence TL improvement should be based on Vehicle configuration and system level target cascaded down from full vehicle target/noise source.

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