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Transmission and Insertion Loss in Commercial Mufflers Using Pink and White Noise Sources

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Abstract

The muffler is an essential component of an automobile, as it reduces noise by reducing the sound pressure level emanating from the engine, and hence reduces sound pollution. Commercial mufflers are generally reactive mufflers with an added absorptive element. The objective of our study is to compare the insertion loss across two different commercial mufflers, using pink and white noise sources, at constant input power values. The pink and white noise sources are derived from Radon Soft, V1.21. The SPL at the output port of the muffler is measured using a sound level meter. The response of two mufflers manufactured by Royal Enfield and fitted to their motorbikes viz. the Classic 350 Bullet (m=3.87) and the Thunderbird (m=4.29), is investigated for insertion loss, bandwidth, and dissipation. The experimentally obtained insertion loss is compared with the theoretical estimates of transmission loss for each of the models, and it is found that both TL and IL show similar results. The resonating length pays an important role in deciding all parameters.

Keywords: Muffler, insertion loss, pink noise, noise pollution, noise reduction

Introduction

Mufflers are an essential part of the exhaust system of automobiles located at the back or on the sides of the vehicles. The gases produced during combustion are released into exhaust system every time the exhaust valve opens, producing a loud noise.

The cost of an automobile is a crucial factor in its design and manufacturing. Hence, the muffler that goes with the exhaust system needs to be cost effective despite the high-density materials that go into its construction. This not only adds to the price of the vehicle but also increases the overall weight, especially in case of motorcycles. Added weight limits acceleration, increases fuel consumption, and decreases mileage [1]. A variety of materials are used depending upon the vehicle and the engine ranging from titanium for strength to carbon alloy for low body weight e.g., aluminium mufflers are lightweight while carbon-steel mufflers are durable.

The engine exhaust noise is minimised by introducing absorptive material in the path of flow of exhaust and using perforated pipes and ducts (Dissipative muffler), or simply by generating noise with opposite phase (Reactive muffler). Chances of creating back pressure are more in second method, as the pressure wave generated gets reflected from end wall, inner barriers, or due to the shape of the muffler [2, 3]. Back pressure in the exhaust system also pushes any unburned intake back into the engine, maintaining an optimum pressure level for optimum power delivery throughout the rpm range. Hence a combination of mufflers is used in most designs [4].

We have used white and pink noise in our investigation as insertion loss is seen to vary considerably with the kind of noise generated during combustion. White noise is a random mix having equal intensity at all frequencies comprised, whereas pink noise is a signal with a frequency spectrum such that the power per frequency interval is inversely proportional to the frequency itself. The engine noise being a combination of frequencies and amplitudes, we chose to examine the transmission and insertion loss of mufflers using white and pink noise. Although, the response of lab grade mufflers to pink and white noise has been investigated earlier [5], the response of commercial mufflers to the same wasn't studied enough. This study compares the insertion loss across two different commercial mufflers using pink and white noise sources. The Insertion Loss is examined keenly so as to realize the true reduction in noise on application of the muffler [6].

Two commercial Royal Enfield mufflers are investigated viz. the "Classic 350 Bullet" muffler (M-1) and the "Thunderbird 350" muffler (M-2) shown in Fig.1. Classic 350 Bullet is powered by 346cc BS6 engine which develops a power of 19.1 bhp and a torque of 28 Nm. And Thunderbird 350 uses a single cylinder, 4 stroke, Twin spark engine 19.8 bhp of power at 5250 rpm and 28 Nm

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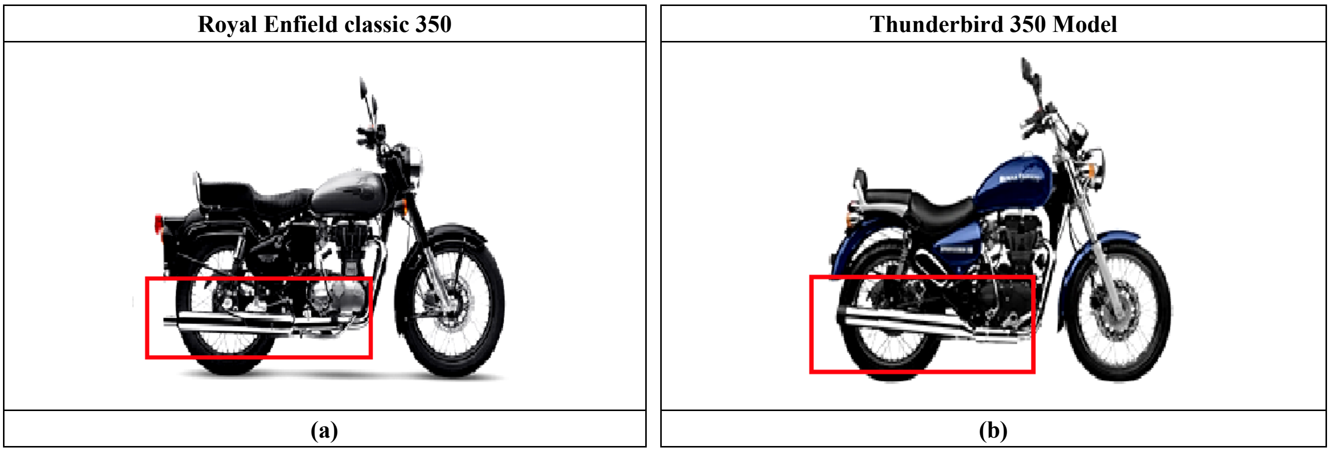

Fig 1: a) Royal Enfield Classic 350 Bullet (M-1) and **b)** Thunder Bird (M-2)

Experimental Setup

Mufflers are studied with respect to two parameters: length of chamber or resonating length (l) and ratio of cross section of chamber to inlet or outlet (m). The two mufflers: M-1 with m=3.87, l=0.33 m (Classic 350 Bullet) and M-2 with m=4.29, l=0.72 m (Thunderbird 350) are subjected to a range of frequencies from 25 Hz to 500 Hz by using a horn driver unit (Ahuja AU-69), driven by an amplifier (Unisound SSB-45M) that derives its input from the frequency generator (Scientific SM5077). The output SPL dBA is measured using the sound level meter (Vernier SLM-BTA) keeping the input level constant at 85 dBA first and then at 95 dBA. The curves are plotted for Insertion Loss (IL) and Transmission Loss (TL) against frequency. The frequency values corresponding to maximum values of IL and TL are noted.

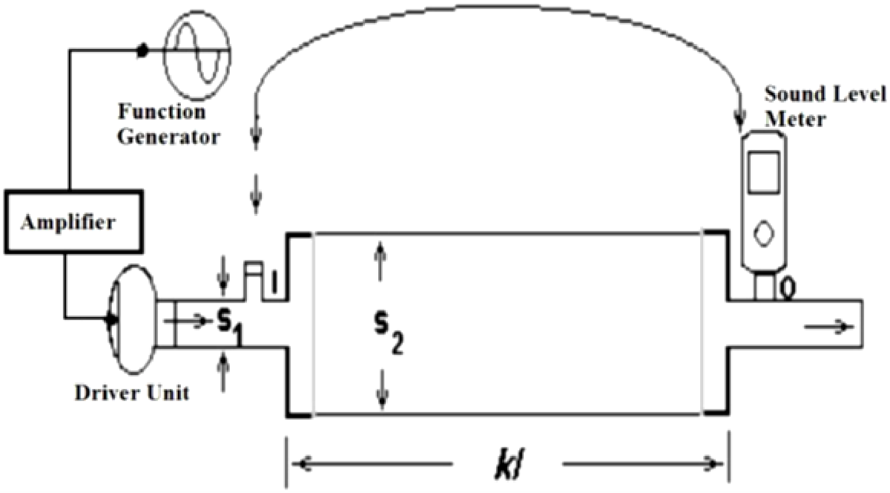

Fig 2: Schematic diagram of muffler setup for calculation of IL

The Radon Soft, V1.21 app is used in place of the function generator for the white and pink noise investigation (Fig.2). The mufflers M-1 and M-2 are studied for white noise and pink noise (150 Hz, 200 Hz, 250 Hz, 500 Hz and 1000 Hz) with regards insertion loss (IL) corresponding to 85 dBA and 95 dBA inputs.

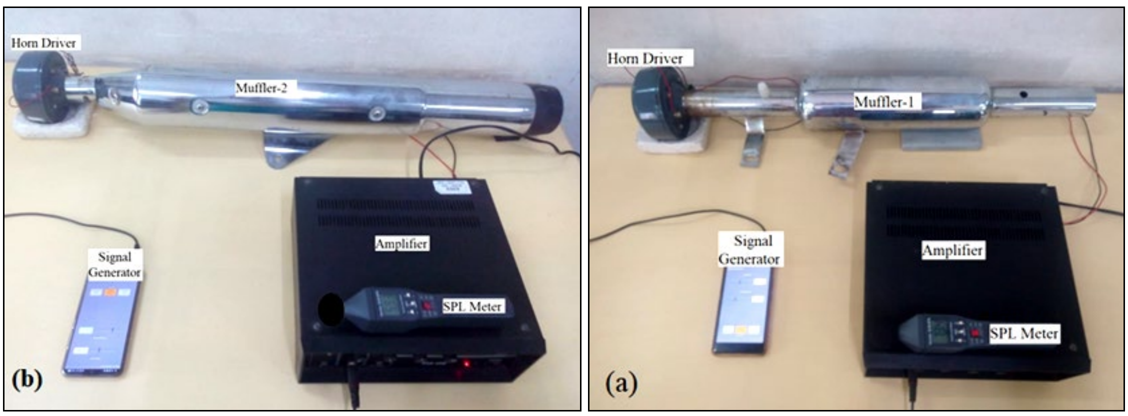

Fig 3: Experimental setup to measure insertion loss for (a) M-1 (b) M-2

Methodology

The SPL is adjusted to 85 dBA at the input port of the muffler for a range of frequencies from 25 Hz to 500 Hz, recording output at output port using a sound level meter and keeping the amplitude handle constant as shown in Fig.3. Insertion loss is determined by taking the difference of SPL dBA values at the input and output ports corresponding to each frequency. The function generator is then replaced by the RadonSoft, V1.21 app for white noise. The amplitude is so adjusted that the SPL is set to 85 dBA at the input port. The corresponding output is recorded at the output port. The insertion loss is determined using these two values. The RadonSoft, V1.21 app source is now set to pink noise generation. The frequency is set to 150 Hz. Amplitude is maintained at 85 dBA at the input port. The corresponding output is measured. Hence, insertion loss is determined. The same is repeated for pink noise by setting frequency values to 200 Hz, 250 Hz, 500 Hz and 1000 Hz. The entire procedure is then repeated for an input SPL of 95 dBA for both M-1 and M-2. The exercise has been repeated more than thrice to arrive at the values reported.

Results and Discussion

1. TL, IL, Bandwidth and Q factor

The transmission loss is calculated at room temperature using the standard equation, Equation-1 [7]. The curve for transmission loss versus frequency gives the frequency value corresponding to the TL_{max} for first harmonic, for each muffler (Table 1).

$$TL = 10\log_{10}\left\{1+\frac{1}{4}\left(m-\frac{1}{m}\right)^2 \sin^2 kl\right\} \qquad \text{Equation-1}$$

Where,

TL is Transmission Loss due to muffler; m = S_2/S_1 (S_2 is area of cross section of chamber and S_1 = area of cross section of inlet pipe); l is the length of the central chamber; k is wave number given as $2\pi/\lambda$.

The TL curves for both M-1 and M-2 are plotted in Fig.4 as

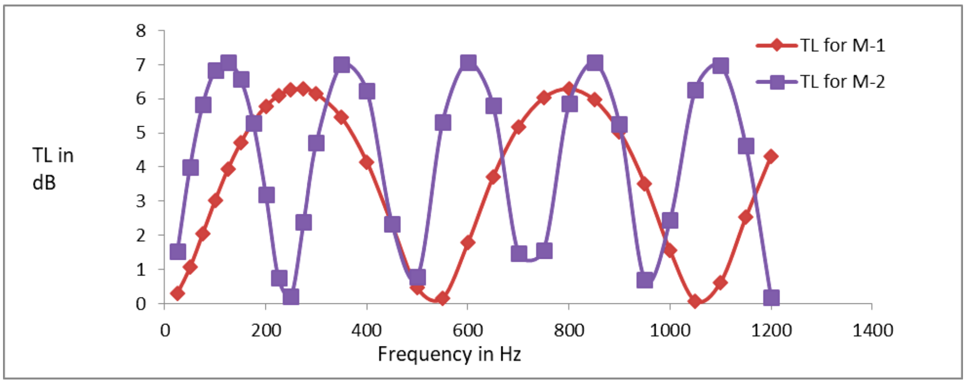

Fig 4: Transmission Loss Curve for M-1 and M-2

Muffler M-2 shows harmonics at half the number of frequency values as compared to M-1. TL for M-2 falls to zero whereas M-1 shows peak values for TL at 250 Hz. Also, TL_{max} increases with increase in 'm'.

The Insertion Loss which is the difference in SPL metre reading at the inlet and at the outlet of the muffler is calculated by using Equation-2 [8].

$$IL = SPL_{i/p} - SPL_{o/p} \qquad \text{Equation-2}$$

The insertion loss is plotted against frequency values. The bandwidth at (IL_{max}-3 dB) is determined. The *Q* factor is determined for each of the mufflers (Table 1).

Table 1: Transmission Loss, Insertion Loss, Bandwidth and Q factor for M-1 and M-2 for (A) 85 dBA input (B) 95 dBA input

A. For 85 dBA Input									
Sr. No.	**Type of Muffler**	**Resonating Length**	**Transmission Loss**		**Insertion Loss corresponding to 85 dBA**				
			TL	**Corresponding Frequency**	**IL**	**Corresponding Frequency**	**Band Width (FWHM)**	**Q Factor**
		m	**dB**	**Hz**	**dB**	**Hz**	**Hz**	
1	M-1 m= 3.87	0.33	6.28	275	8.9	175	61.84	2.8299
2	M-2 m = 4.29	0.72	7.07	125	15.8	150	13.65	10.99

B. For 95 Dba Input								
Sr. No.	**Type of Muffler**	**Resonating Length**	**Transmission Loss**		**Insertion Loss corresponding to 95 dBA**			
			TL	**Corresponding Frequency**	**IL**	**Corresponding Frequency**	**Band Width (FWHM)**	**Q Factor**
		m	**dB**	**Hz**	**dB**	**Hz**	**Hz**	
1	M-1 m= 3.87	0.33	6.28	275	13.5	175	59.54	2.939
2	M-2 m = 4.29	0.72	7.07	125	14.1	275	19.19	14.33

The peak in the TL (TL_{max}) occurs at 275 Hz having the value 6.28 dB for M-1, and at 125 Hz having value 7.07 dB for M-2; irrespective of the input value.
The Insertion Loss peak appears at 175 Hz with 8.9 dBA for M-1, and at 150 Hz with 15.8 dBA for M-2 for 85 dBA input; whereas for 95 dBA input, M-1 shows a peak at 175 Hz with 13.5 dBA and M-2 shows a peak at 275 Hz as the fundamental frequency with 14.1 dBA.

2. Response to Pink and White noise

Response of both the mufflers to Pink and White noise are given in table 2.

Table 2: Response for Pink and White Noise for M-1 and M-2 for (A) 85 dBA input (B) 95 dBA input

A. For 85 dBA input										
Sr. No.	**Type of Muffler**	**Resonating Length**	**Insertion Loss corresponding to 85 dBA**							
			Pure Tone		**Pink Noise at 150 Hz**	**Pink Noise at 200 Hz**	**Pink Noise at 250 Hz**	**Pink Noise at 500 Hz**	**Pink Noise at 1 KHz**	**White Noise**
			IL Max	**Corresponding Frequency**						
		m	**dB**	**Hz**	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**
1	M-1 m= 3.87	0.33	8.9	175	10.1	9.6	9.9	9.6	10.2	10
2	M-2 m = 4.29	0.72	15.8	150	14.6	14.2	9.5	12.5	14.1	17.4
			15.6	300						

B. For 95 dBA input										
Sr. No.	**Type of Muffler**	**Resonating Length**	**Insertion Loss corresponding to 95 dBA**							
			Pure Tone		**Pink Noise at 150 Hz**	**Pink Noise at 200 Hz**	**Pink Noise at 250 Hz**	**Pink Noise at 500 Hz**	**Pink Noise at 1 KHz**	**White Noise**
			IL Max	**corresponding Frequency**						
		m	**dB**	**Hz**	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**
1	M-1 m= 3.87	0.33	13.5	175	14	12.8	13.1	12.9	12.9	14
2	M-2 m= 4.29	0.72	14.1	275	15.3	11.9	17.7	14.2	12.6	17.8
			13.5	500						

M-1 shows a consistent value for IL for all selected frequency values of pink noise, in the same range as that of white noise but higher than the pure tone. M-2 shows higher value of IL for pune tone and white noise than pink noise.
For pink noise: IL value for M-1 first decreases from 10.1 dBA (150 Hz), falls to 9.9 dBA at 250 Hz, and then increases to 10.2 dBA at 1.0 KHz. IL value for M-2 first decreases from 14.6 dBA (150 Hz), falls to 9.5 dBA at 250 Hz, and then increases to 14.1 dBA at 1.0 KHz. However, at 250 Hz, both the mufflers show nearly equal values of IL (Fig.5).

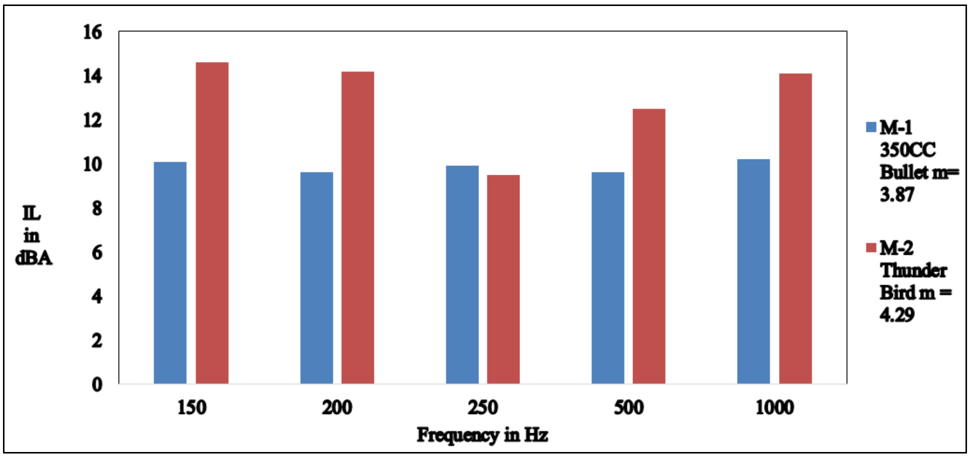

Fig 5: Bar Chart showing response of M-1 and M-2 for different frequencies of Pink Noise at 85dBA

M-1 shows consistent values for IL for all selected frequency values of pink noise, in the same range as white noise and pure tone. M-2 shows higher value of insertion loss for white noise than pure tone For pink noise: Unlike 85 dBA, for M-2, IL value for 95 dBA input first increases from 15.3 dBA (150 Hz), becomes highest at 250 Hz (17.7 dBA) and again decreases to 12.6 dBA at 1.0 KHz. The same is represented graphically (Fig. 6) as:

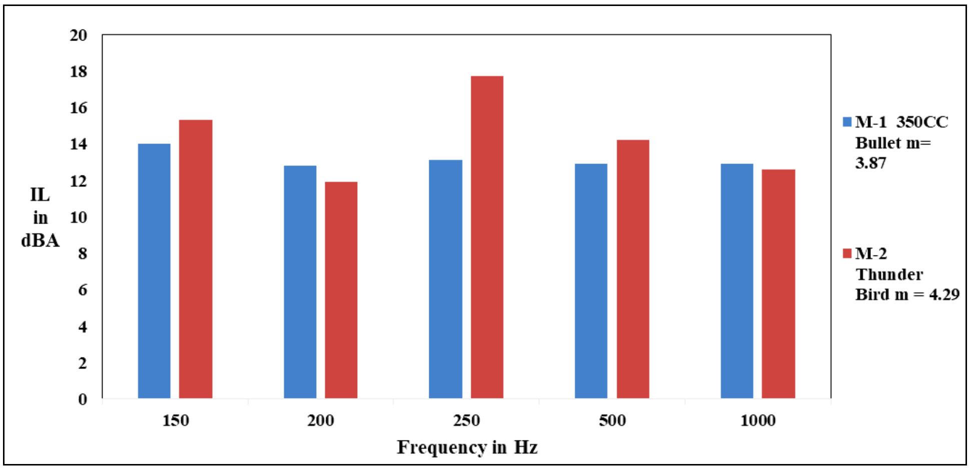

Fig 6: Response of M-1 and M-2 for different frequencies of Pink Noise at 95 dBA

Conclusion

Thunderbird (M-2) shows a narrow bandwidth and hence a greater Q as seen in Table 1, meaning it performs better for a selected range of frequencies which is also observed when the white and pink noise sources are used (Fig.5 and 6). This is due to a higher value of ratio of cross section 'm' and length more than twice in comparison to that of Classic 350 Bullet (M-1). M-1 shows a uniform response for all frequencies of pink noise (Fig.5 & 6) and has wider bandwidths and a smaller Q as seen in Table 1.

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