Predictive Simulation of Analyzing Orifice Noise in Exhaust System of a Passenger Car

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Abstract— An IC Engine is major source of noise pollution, whereas exhaust noise play major contribution. Noise generated in engine is due to combustion of fuel & also Flow noise which is caused by turbulent gas which is one of the dominating noise sources on high performance turbo charged and naturally aspirated engines. Main function of Exhaust system is to expel the hot exhaust gases to the rear of vehicle (away from passenger compartment) & also to muffle the engine noise. Muffling of noise is majorly done by muffler/ Silencer, but other components of exhaust system also contribute in reducing the noise. This paper investigates the effect of Tail pipe on exhaust noise. The mechanisms of engine combustion noise via the exhaust system and flow excited noise are analysed. Several Geometric parameters such as pipe length, diameter, twin tail pipe and Y tail pipe have been changed simulation has been done to predict the effect on orifice noise. The length of tail pipe influences sound order distribution that influences customer responsiveness of sound.

Key words: Exhaust System, Orifice Noise, Tail Pipe Noise, Noise Reduction

I. Introduction

An automobile gets its power from engine, where chemical energy is get converted into mechanical energy or power. Inside the engine cylinder fuel is burned with explosion and release high amount of energy. This repeat explosion creates the high and low pressure pulse into the exhaust system through exhaust valves. This pressure pulse when comes out of exhaust tail pipe and hit our ear drum we feel it as sound. As the engine RPM increases so the pressure fluctuation and so the noise is of higher note. Fig 1. Shows the various noises in vehicle, the major contribution of noise is engine & exhaust. Fig. 2 shows the transfer path of noise from engine & exhaust system, this exhaust noise is silenced by Exhaust system, mainly by mufflers.

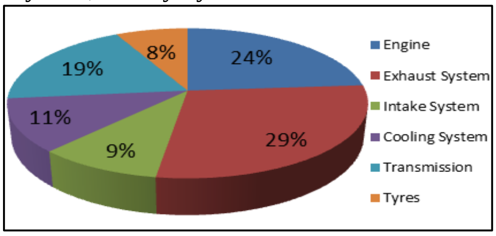

Fig. 1: Drive by Noise Contribution

Engine noise reduction or cancellation can be achieved either by absorbing or by cancellation with opposite phase sound wave. Muffler or exhaust system geometry also contributes in noise reduction as due to change in geometry contributes in loss of sound pressure energy termed as transmission loss.

Sound quality is important attribute that relate to customer satisfaction. The noise produced by engine has whole and half order. Flow noise from exhaust system to be minimized as far as possible, but this aim is limited by packaging constraints in the vehicle underfloor and it is contradicting to the damping of I.C engine combustion noise. Large tube diameters are beneficial to decrease flow noise, but on the other hand large diameters are increasing the tail pipe noise content caused by IC engine combustion. Additionally tube diameters are restricted by the design space in the underfloor. Therefore it is essential to investigate flow noise in exhaust system already in concept phase for an optimal utilisation of the availability vehicle under layout. This is essential to reduce the weight and cost to optimize the performance of exhaust system.

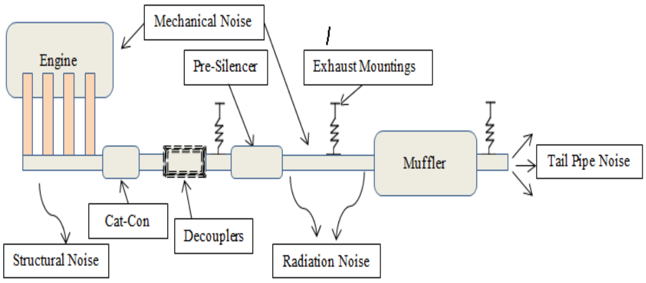

Fig. 2: Noise Transfer Path.

Acoustic performance of an exhaust system also depends on exhaust tail pipe design. Understanding tail pipe options and orifice noise is essential for exhaust control when you don’t have enough options left due to packaging constraints. Automotive industries are finding increasing importance in focusing on sound quality of vehicle to maintain a competitive advantage. Exhaust tail pipe noise is one of the most important noise sources relating customer satisfaction and sound quality.

II. Literature

The attenuation of a muffler which consists of a single expansion chamber is given by the following formula

$$= 10log_{10}\left[1+\frac{1}{4}\left(m-\frac{1}{m}\right)^2 sin^2 kl_e\right] \quad (1)$$

m = expansion ratio
l_e = length of pipe

This equation indicates that the attenuation is dependent on the cross section of chamber & the length, the ratio m (ratio of bigger dia. To lower dia. D1/D2) is directly affecting attenuation, ie. More the difference in the dia. More will be the noise reduction, similarly length of pipe also having cyclic relation with attenuation more the length more will be the band width of attenuation curve.

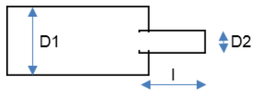

Fig. 3: Schematic Diagram of chamber & tailpipe

Tail pipe dia & length can reduce the noise based on equation above, but Exhaust tail pipe will have resonances that can amplify engine tones. Amplification of noise can be avoid by using short tail pipe or size L to 1/4 wavelength (λ/4)

$$f_n = nc/(2L) \qquad (2)$$

Where: f_n is resonance frequency of pipe
n = 1, 2, 3 …
C is speed of sound
L is length of pipe (ft)

The resonance occurs when L = nl/2, so this tail pipe length should be avoided at all times

Exhaust Noise is usually measured in the near field of tail pipe orifice at full load or defined partial load. Fig 4 shows a typical noise test of tail pipe orifice.

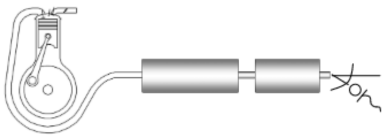

Fig. 4: Tail Pipe Noise measurement Test Set Up

III. ANALYSIS CONSIDERATIONS

For analysis an 1.4L 4 cylinder Gasoline Engine was considered with different cases as shown in Table 1. Base muffler design was considered with the internals as show in Fig. 6

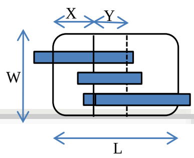

Fig. 5: Base Muffler Design

(L=350mm, W=140mm, X=100mm, Y=90mm, Pipe Dia = 35mm)

Different case are taken and effect of the cases on orifice noise is been carried out.

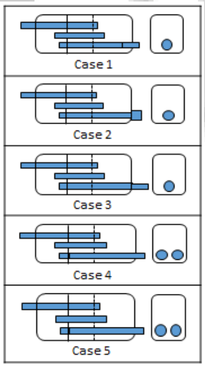

Fig. 6: Schematic Diagram of Different Cases

Case	Description	Tail Pipe Dimensions	
		Diameter (mm)	Length (mm)
1	Base (Internal Pipe dia same as tail pipe dia.)	38	150
2	Diameter Same, Length Increased	38	300
3	Diameter increased, Length same as of Base	48	150
4.1	Twin Tail Pipe	27	150
4.2		36	150
5.1	Y Type Tail Pipe	36	150
5.2		27	150

Table 1: Cases for different Tail Pipe Options

IV. RESULTS

The effect of tail pipe geometry is analysed using simulation, simulation is run for the different cases as explained above, the results are very encouraging & showing that only by changing the geometrical parameter of tail pipe we can reduce the overall noise and also in order noise.

The effect of changing the tail pipe geometry on overall noise is compared with base system,

Case 1 Base muffler – avg. overall noise is 68.34dB, but at lower rpm (1000 – 1500) the noise level is nearly 73.5dB

Case 2, with increased tail pipe length & keeping same tail pipe dia showing improvement in noise reduction, avg. overall noise level is 66.6 which is 2.5% lower than base muffler, also at lower rpm there is noise reduction by 3.5 dB, nearly about 5%.

In case there is space limitation for increasing the tail pipe length, but there is scope of packaging twin tail pipe, then Case 7 shows which is Y shape twin tail pipe showing better results, avg. overall noise level is 66 which is 3.5% lower than base muffler, also at lower rpm there is noise reduction by 4.2 dB, nearly about 5.6%.

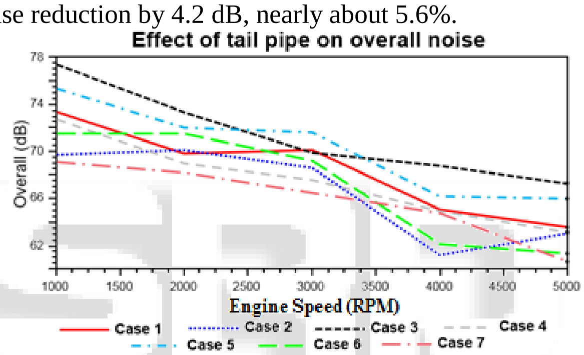

Fig. 7: Graph 1: Overall noise vs RPM

Changing the tail pipe also contributing in order noise, below results shows that there is remarkable improvement in 2nd order noise,

Case 2 is giving best result, the avg. noise at 2nd is reduced by 7.6 % i.e. by 5dB, and also at lower rpm noise reduction is by 7%.

Case 7, which is Y shape twin tail pipe showing better results, avg. overall noise level is 63 which is 5% lower than base muffler, also at lower rpm there is noise reduction by 4.2 dB, nearly about 6%.

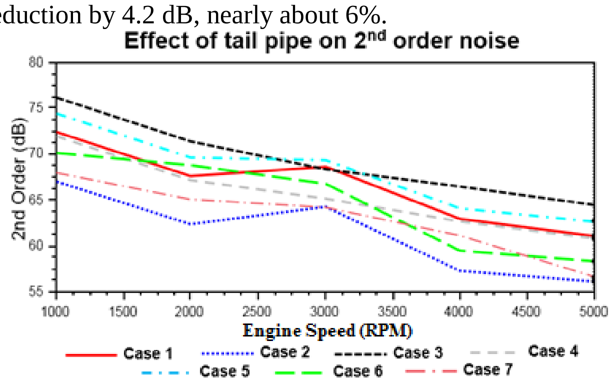

Fig. 8: Graph 2: 2nd order noise vs RPM

Changing the tail pipe also contributing in 4th order noise, below results shows that in case 2 there is no noise reduction as of base muffler but at lower rpm it is showing better noise attention.

At lower rpm (1000 – 1500) noise reduction is almost by 10%

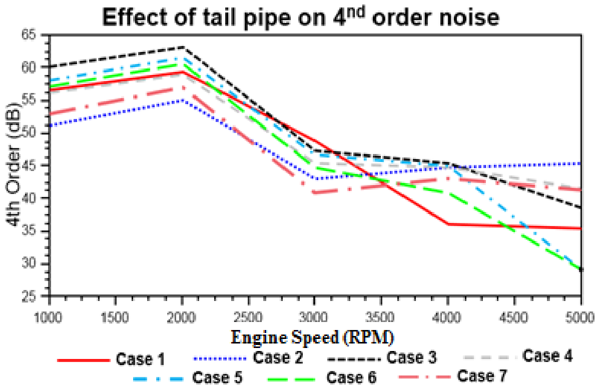

Fig. 9: Graph 3: 4^{th} order noise vs RPM

Case 7, which is Y shape twin tail pipe showing better noise reduction, avg. 4^{th} order noise level is 47 which inline to base muffler, but at lower rpm there is noise reduction by 3.8 dB, nearly about 6%.

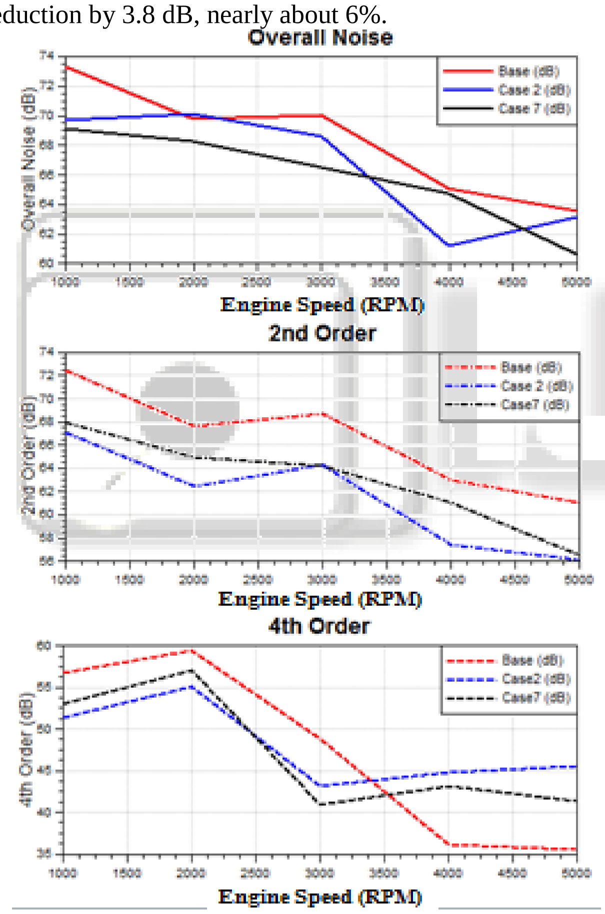

Fig. 9: Graph 4: Summary of Optimized options

V. CONCLUSION

The various dimensions of the tail pipe are varied by keeping muffler dimensions constant and then the effect on overall & order noise is observed. It can be seen that the design of tail pipe also contributing in noise reduction at overall & order noise level.

The orifice noise, & 2^{nd} is reduced by 2.5% & 7.6% respectively, whereas 4^{th} order noise is inline or better than the base option if the length of tail pipe is doubled as in case 2.

If packaging space is not available then Y shape twin tail pipe with same length & same pipe cross-section Area (case 7) shows that, the orifice noise & 2^{nd} order noise is reduced by 3.5% & 5% respectively, whereas 4^{th} order noise is inline or better than the base option.

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