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Re-Engineering of Auto Rickshaw Muffler

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Abstract: In automobiles, the exhaust sound is the major source of noise pollution. In order to minimize this noise, muffler should be designed with considering firing frequency of engine, backpressure and manufacturing cost. .In this paper, we made a new design of a Piaggio Ape's muffler to reduce exhaust noise. We have recalculated the dimensions of the muffler and its internal parts for maximum insertion loss. We have used part geometries like fishtailing, expansion cone etc. Based on new muffler design parameters, a model is fabricated and tested.
Keywords: Muffler, Exhaust sound, Backpressure, Noise pollution, Chamber.

I.   INTRODUCTION

The design of mufflers has been a topic of great interest for many years and hence a great deal of understanding has been gained. Most of the advances in the theory of acoustic filters and exhaust mufflers have come about in the last four decades. Hence the good design of the muffler should give the best noise reduction and offer optimum backpressure for the engine. Moreover, for given internal configuration mufflers have to work for a broad range of engine speed.

The base construction of muffler usually consists of the circular or tubular metal jacket, perforated tubes, and the expansion chamber. The arrangement of these components will guide the exhaust gas to flow from the inlet pipe of the muffler to the outlet. Inside the silencer, the noise from the exhaust gas will be canceled out by the basic physical principle based on noise cancellation before the gas flows out to the atmosphere. The noise cancellation will reduce the noise that radiated by the vehicle to the surrounding. The performance of the muffler is based on acoustical and backpressure. Acoustic performance is defined as the sound level measured in decibels. The backpressure is the extra static pressure exerted by the silencer.

II.   PRESENT CONDITIONS

Ape Xtra LD is one of the commercial vehicles of Piaggio. Its engine creates noise above 100 dB. Generally, a better silencer attains attenuating sound & also backpressure. So, the aim of the project to reduce the sound level of auto rickshaw silencer by 5db and to study the acoustical performance.

III.   METHODOLOGY

We have gone through following steps:
1) First, we studied the existing muffler design. Then we studied the general phenomenon and considerations to minimize the exhaust noise.
2) Then we generate some possible designs, we tried to add some innovative geometries in it and after the careful consideration, we finalized one design.
3) Then we calculated the dimensions of all internal and external parts.
4) Then based on calculated dimensions a model is fabricated and tested.
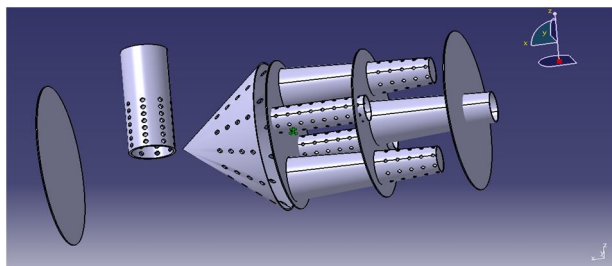
A. Design Iterations
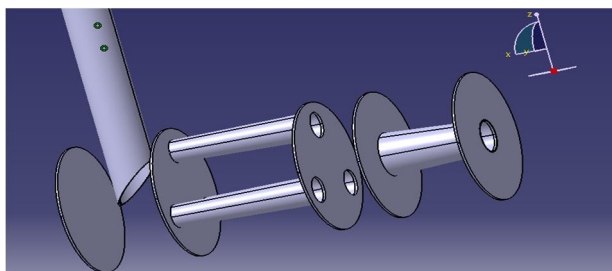
Design 1
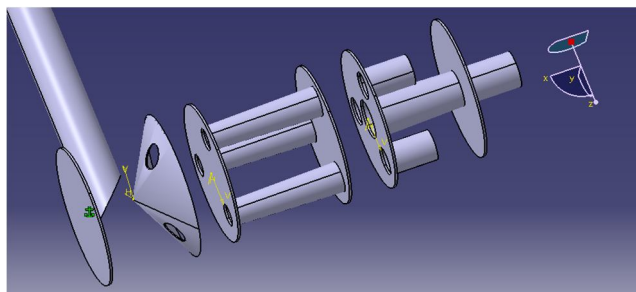
Design 2

Design 3

From above all these designs we selected design 3, it works as follows;

Gases from the exhaust valve of the IC engine flows towards catalytic converter and then moves towards silencer's inlet pipe. It enters into the first chamber through the inlet pipe which is having perforated holes on its periphery. It moves towards the second chamber through the perforated holes present on the cone. At the back of the cone, a low-pressure region is generated which sucks the gases into the second chamber. The second chamber has two fishtail pipes converging at the outlet. It has an extruded part beyond the second chamber. This section has perforated holes on its periphery. Through these holes, the gases are passed in the third chamber. The second baffle plate has two holes of diameter 25 mm. Gases in the third chamber flow back into the previous chamber through these two pipes. Because of this muffling of gases take place. These two straight pipes have perforated holes on its periphery. Gases come out of these perforated holes and enter into the fishtail pipe which ends at the outlet of the silencer.

B. *Advantages*
1) The inlet pipe has perforated holes on its periphery which increases attenuation loss.
2) It has cone like structure which enhances the sound reduction technique.
3) At the back of the cone, a low pressure region is generated which sucks the gases into the second chamber and decreases the back pressure as well.
4) It has fishtail pipes which are very useful in decreasing the sound levels. The fishtail pipes have perforated holes over its periphery which decreases sound.
5) Helmholtz resonator is used which increases attenuation loss.

IV. CALCULATIONS FOR MUFFLER DESIGN 3

A. *The Following Points Are Considered As Guidelines To Designing Of Muffler* _ [16]
1) An angle between the diverging walls of about 6 degree – 10 degree gives best diffuser performance.
2) For a given area change per unit length of duct, diffuser of circular cross section gives the best effectiveness ,with square cross sections next.
3) For most commonly used area ratios an abrupt area increase result in less total pressure loss than a diffuser with wall angle greater than 40 degree – 50 degree.
4) The material used to guide the exhaust flow and sound waves to escape, is usually perforated steel with an open area of approximately 20%. _[1]
5) Lightness could be possible if the thickness is decreased or the volume is reduced. However, this causes high back pressure. _[9]

B.   Muffler Volume Calculation   _[8]

Engine Data:-

Bore (D)=86mm

Stroke Length = 75mm

No of Cylinders (n) = 1

Engine Power (p) =5.82Kw at 3600 rpm

Engine Swept Volume =0 .25×3.14×D×D×L

$\quad\quad\quad$ =0.25×3.14×86×86×75

$\quad\quad\quad$ =0.43543 Liter

Engine Volume to be considered for calculation = 0.5×swept volume × n

$\quad\quad\quad$ =0.5× 0.43543× 1

$\quad\quad\quad$ =0.217715 litre

Now, Silencer Volume (Volume of silencer must be at least 12 to 25 times the engine volume i.e. factor considered is 25)

$\quad\quad\quad$ = 25×0.217715

$\quad\quad\quad$ = 5.442875 litre

C.   Four Stroke Engine Airflow Calculations

$$Intake\ Airflow = \frac{Engine\ Size(CID) \times RPM}{3456} \times \text{Volumetric Efficiency}$$

$$Intake\ Airflow = \frac{26.6064 \times 3600}{3456} \times 0.9$$

$$=249.435\ \text{CFM}$$

Here,

Engine Size =436 CC=26.6064 CID

$\quad\quad$ _Volumetric Efficiency for naturally aspirated diesel engine=90 %

Now, Exhaust flow = $(\frac{Engine\ temperature+460}{540}) \times Intake\ Airflow$

$=(\frac{1000+460}{540}) \times 249.435$

= 674.39 CFM

Now, Exhaust gas Velocity = $\frac{Exhaust\ flow\ rate\ (CFM)}{Silencer\ inlet\ pipe\ area\ (ft^2)}$

$=\frac{674.398}{0.01318579}$

=51145.842 ft/min

D.   Calculation For Pressure Drop   _[15]

Now,

Exhaust Temperature of diesel Four Stroke naturally aspired engine=1000 degree F

Maximum back pressure required= 3" Hg = 0.10159 bar

Now, Pressure Drop (ΔP) = $Cp \times (\frac{V}{4005})^2 \times (\frac{530}{T\ (degree\ F)+\ 460})$

$= 0.8 \times (\frac{51145.842}{4005})^2 \times (\frac{530}{1000+\ 460})$

= 47.362 inches of water

= 0.117855601 bar

E.   Selection of Muffler Grade   _ [8]

Step1) Unsilenced Noise Level (UNL) = 110 dB

Step 2) Calculation of Exhaust Noise Calculation (RNC) criteria,

$\quad$ We assume that Receiver noise criteria (RNC) = 85 dBA

$\quad$ Hence, ENC = RNC - 5

$\quad$ ENC = 85 - 5

ENC = 80

Step 3) Insertion Loss = UNC - ENC -5

= 110 – 80 – 5

=25 dBA

Now, according to Insertion Loss it is a 'Residential Grade' type muffler,

So, according to ASHARE technical Committee 2.6 for 'Residential Grade' type muffler,

Insertion Loss	20 to 30 dB
Body/Pipe	2 to 4
Chamber Length/pipe	6 to 10

Table 1: Residential Grade Type Muffler

1) Chamber Length Selection _[15]

According to ASHARE technical Committee 2.6

$6\times d_{exhaust} \leq L \leq 10 \times d_{exhaust}$

$6 \times 35 \leq L \leq 10 \times 35$

$210\ mm \leq L \leq 350\ mm$

a) Selection Of Chamber Length Considering Exhaust Gas Temperature

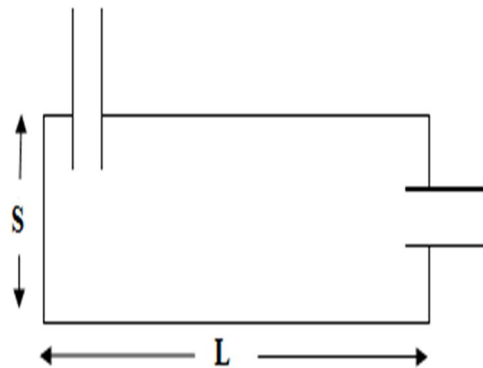As we already assumed that maximum exhaust gas temperature

=1000 degree F

=1459.67 degree R

Fig. 1 Muffler Layout

Limit of length,

$0.5(\frac{49.03 \times \sqrt{R}}{2\pi \times f}) \leq L \leq 2.6 (\frac{49.03 \times \sqrt{R}}{2\pi \times f})$

$0.5(\frac{49.03 \times \sqrt{1459.67}}{2\pi \times 550}) \leq L \leq 2.6 (\frac{49.03 \times \sqrt{1459.67}}{2\pi \times 550})$

$0.2710\ feet \leq L \leq 1.4093\ feet$

$82.6\ mm \leq L \leq 429.55\ mm$ Attenuation frequency f =550 Hz

Hence according to these two limits and available space in vehicle, L=350 mm

Now, length of each chamber as per frequency to attenuate sound,

Let the noise frequency range be 700 Hz to 1200 Hz; assume velocity of sound c=330 m/s.

For four chambers we selected 800 Hz, 900 Hz, 1000 Hz, 1100 Hz and for further calculations as follows,

Chamber No.	Frequency, f (Hz)	Wavelength (m) $\lambda = \frac{c}{f}$	Wavelength, λ (mm)	Calculated length of chamber	Selected length of chamber
1	800	0.413	413	103.25	105
2	900	0.367	367	91.25	90
3	1000	0.330	330	82.5	80
4	1100	0.300	300	75	75

Table 2: Length of chamber

Total length of muffler = 105 + 90 + 80 + 75 = 350mm

2)   Selection Of Body Diameter

Body diameter from muffler volume calculation

Muffler Volume (Vm) = $\frac{(\pi \times L \times S^2)}{4}$

$5442875(mm^3)$ = $\frac{(\pi \times 350 \times S^2)}{4}$

S =140.71 ~150 mm

3)   Tail Pipe Length,

Exhaust tail pipe will have resonance that can amplify engine tones.

To avoid Amplification of tones use short tail pipe length,

$(l_{tail\ pipe}) = (\frac{Speed\ of\ sound}{4 \times f} - \frac{d_{inlet}}{2}) \times 5$

$= (\frac{1082.68}{4 \times 550} - \frac{30}{2}) \times 5$

= 72.5 mm   _(Speed of Sound =330 m/s=1082.68 FPS)

4)   Calculation Of Perforated Holes

Diameter of perforated holes =1.29 $\times \sqrt{N_{cylinder}}$ to 2 $\times 1.29 \times \sqrt{N_{cylinder}}$

$= 1.29 \times \sqrt{1}$ to $1.29 \times \sqrt{1} \times 2$

$= 1.29$ ~2 mm to 4 mm

a)   No. of Perforation Holes On Expansion Cone

Area of C/S of Inlet Pipe = Total Area of Perforation Holes

$\Pi \times (35/2)^2 = Nc \times \Pi \times (4/2)^2$

Nc = 76.56 ~ 77, of diameter 4 mm

b)   No. Of perforation holes on extended pipe

Total Area of C/S of baffle Pipe = Total Area of Perforation Holes

$2 \times \Pi \times (32/2)^2 = 2 \times Nc \times \Pi \times (4/2)^2$

Nc = 64, of diameter 4 mm

c)   No. Of perforation holes on bypass pipe

Total Area of C/S of bypass Pipe = Total Area of Perforation Holes

$2 \times \Pi \times (25/2)^2 = Nb \times 2 \times \Pi \times (3/2)^2$

Nc = 69.44 ~ 70, of diameter 3 mm

5)   Calculation Of Bypass Tubes

Baffle pipe design-

Area of inlet pipe = Total area of baffle pipe

$\frac{\pi}{4} \times d_{inlet}^2$ =No. of tubes $\times \frac{\pi}{4} \times d_{baffle}^2$

$\frac{\pi}{4} \times 35^2 = 2 \times \frac{\pi}{4} \times d_{baffle}^2$

d_{baffle} = 24.74 mm = 25 mm

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III. TESTING

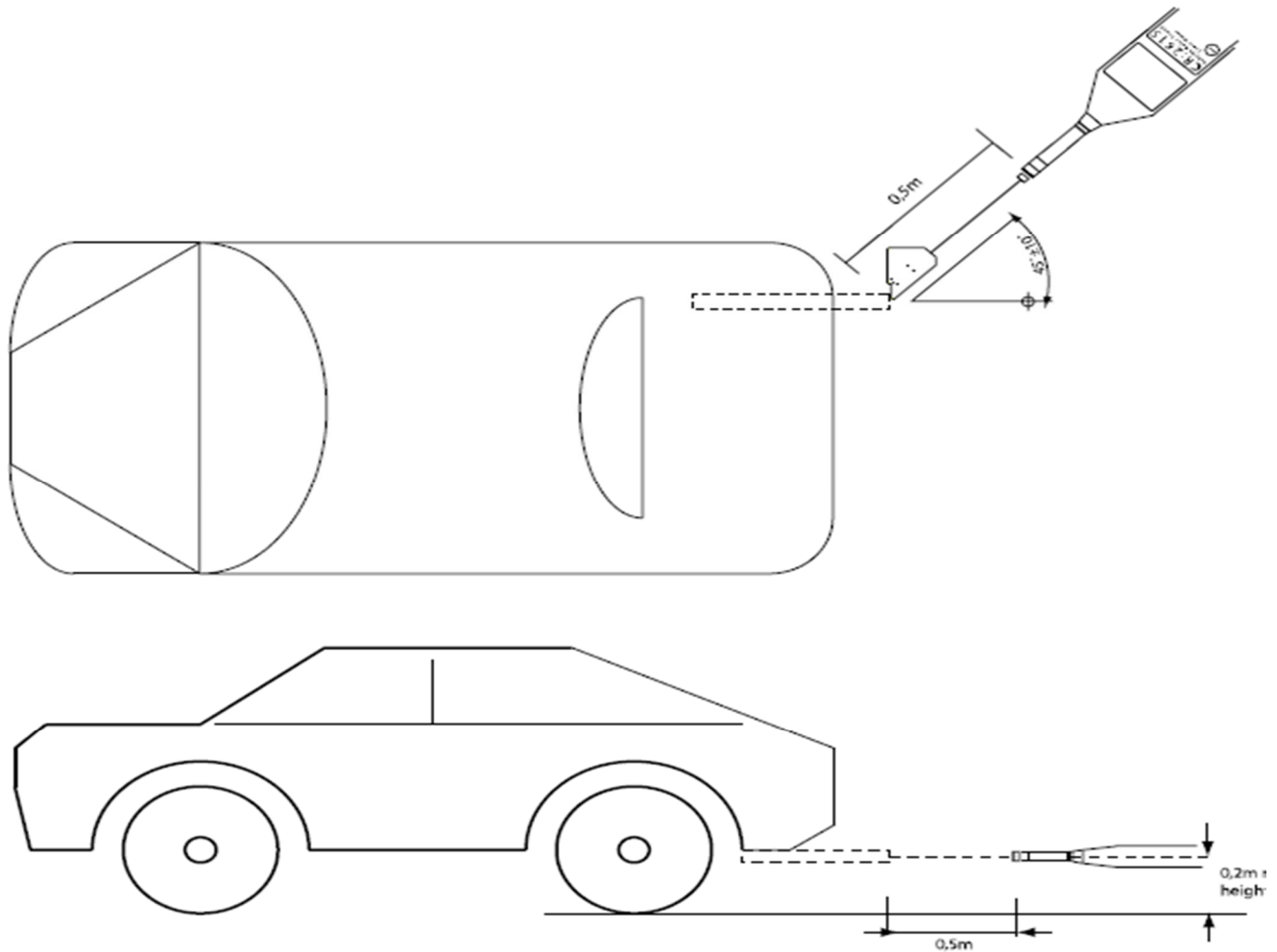*A. Directions For Taking The Decibel Readings*

Fig. 2: Directions of taking the decibel reading

B. Measured decibels with Existing Muffler & New Muffler

Position of Decibel meter	Neutral/ Acceleration	Distance between exhaust pipe and decibel meter (feet)	Sound of Existing Muffler in dB	Sound of New Muffler in dB
Front	Neutral	1	97.8	92.8
		2	94.6	86.4
		3	90.8	84.3

Table 3: Reading Table A

Position of Decibel meter	Neutral/ Acceleration	Distance between exhaust pipe and decibel meter (feet)	Sound of Existing Muffler in dB	Sound of New Muffler in dB
Left	Neutral	1	100.1	95.3
		2	97.1	91.5
		3	93.1	87.5

Table 4: Reading Table B

Position of Decibel meter	Neutral/ Acceleration	Distance between exhaust pipe and decibel meter (feet)	Sound of Existing Muffler in dB	Sound of New Muffler in dB
Front	Acceleration	1	104.6	101.4
		2	101.5	92.7
		3	95.2	91.0

Table 5: Reading Table C

Position of Decibel meter	Neutral/ Acceleration	Distance between exhaust pipe and decibel meter (feet)	Sound of Existing Muffler in dB	Sound of New Muffler in dB
Left	Acceleration	1	107.2	102.3
		2	105.9	98.3
		3	103.0	94.9

Table 6: Reading Table D

Reading at the mouth of Exhaust pipe for Existing Muffler: 101.2dB

Reading at the mouth of the Exhaust pipe for New Muffler: 96.7 dB

IV.   CONCLUSION

A. A muffler has been designed to meet the requirements like adequate insertion loss, minimal backpressure, space constraints and durability and produce the minimal sound. Hence the good design of the muffler gives the best noise reduction.

B. The sound levels have been decreased by 4.5 dB keeping permissible backpressure.

C. After installing at the position of the existing muffler, the maximum sound level of new muffler is 102.3 dBA.

D. The variation of old and new muffler minimum insertion loss is 3.2dBA.

E. The only drawback is that its size has been increased which resulted in increase in material cost, thus the overall cost of the muffler.

F. The production cost can be reduced by avoiding extra material and manufacturing it in mass quantity.

V.   ACKNOWLEDGMENT

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