Design, Development & Analysis of Resonator Chamber Type Muffler for I.C Engine

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Abstract— Man's desire for a pollution free atmosphere needs reduction or control of noise pollution from the sources such as automobile engines, power plants and Industrial installations. The principal sources of noise in automotive engines are intake noise, radiator noise, combustion noise, exhaust noise, etc. Out of these, exhaust noise is predominant and it is to be controlled. Physiologically and psychologically effects are seen as pollution affects human beings. So the silencer or muffler is a part of the exhaust system on an automobile that plays a vital role in reduction of the noise and pollution. The main objective of this study is to propose an exhaust silencer or muffler design which one reduces a large amount of noise level and back pressure of the engine. The present paper deals with the design analysis and performance evaluation of the silence develop with features of noise and pollution reduction for an agriculture application engine. The system draws inspiration for a design named Helmholtz silencer which uses a resonating chamber.

Key words: Automobile Engine, Exhaust Muffler, Resonating Chamber, Pollution Control, Noise

I. INTRODUCTION

Exhaust system is effectively a series of pipes and boxes specially designed to channel emissions away from the front of the vehicle, reduce engine noise and maintain optimum fuel efficiency [1]. All exhausts produce 6 gases as emissions; of the six three are less harmful (nitrogen, carbon dioxide and water vapour) and three are toxic (carbon monoxide, nitrogen oxide and nitrogen monoxide). The job of the exhaust, catalytic converter and its monitoring system is to maintain the correct balance of emissions, check the engine is running efficiently and move the emissions away from the vehicle occupants. Under existing regulations a Police officer can warrant the removal of any vehicle from the roadways on the suspicion that it is producing excessive amounts of pollutant gases from the exhaust. Also, if your vehicle exhaust system is broken and noisy your vehicle will come under police scrutiny. Your vehicle will also fail its MoT test if the exhaust system has a fault resulting in incorrect emissions levels being recorded. Mufflers are part of your vehicle's exhaust system and are located at the rear, bottom of your vehicle [2]. They aid in dampening vehicle emissions and engine noise. They are made of steel and are coated with aluminum to provide protection from the heat and chemicals released from the exhaust system. Mufflers are used mainly to dissipate the loud sounds created by the engine's pistons and valves. Every time your exhaust valve opens, a large burst of the burnt gases used during your engine's combustion is released into the exhaust system. This release of gases creates very powerful sound waves; a muffler dissipates the sound waves created by your engine [3].

II. MUFFLER SELECTION

In order to select a suitable muffler type, some basic information are necessary regarding how industrial mufflers work. Industrial mufflers, (and mufflers in general), attenuate noise by two fundamentally different methods [4]. The first method, called reactive attenuation - reflects the sound energy back towards the noise source .The second method, absorptive attenuation – absorbs sound by converting sound energy into small amounts of heat. There are three basic industrial muffler types that use these methods to attenuate facility noise – reactive silencers, absorptive silencers and anyone or both of them combined with resonator .The proper selection of a muffler is performed by matching the attenuation characteristics of the muffler to the noise characteristics of the source, while still achieving the allowable muffler power consumption caused by muffler pressure drop. Fortunately, industrial noise sources separate primarily into three different categories with specific characteristics [5]. The first category covers sources that produce mainly low-frequency noise, yet can typically tolerate relatively high-pressure drops. Engines, rotary positive blowers, reciprocating compressors, and rotary screw compressors are types of these sources. It is simply the nature of these machines to produce low-frequency noise and have pressure-volume relationships that are quite tolerant of system pressure drop. These machines are perfectly suited for reactive (chambered) silencers. The second category of noise sources are those that produce mainly high-frequency noise and have performance that is very sensitive to system pressure losses. These sources are almost always moving or compressing a fluid with spinning blades. Examples include centrifugal fans, compressors, and turbines. By definition, this type of equipment is best treated with absorptive silencers for both low and higher temperature applications. Resonators can be used to remove tones from the exhaust spectrum. There are two major industrial facility applications that fall outside these categories, and are best silenced with specific combination reactive-absorptive mufflers. These sources are high-speed rotary positive blowers and high-pressure vents. Both sources have substantial high and low frequency noise content, and can tolerate moderate pressure drop. As a general rule, reciprocating or positive displacement machines should be attenuated with reactive silencers, and centrifugal equipment should use absorptive silencers. For all remaining major noise sources, combined reactive-absorptive silencers are appropriate with many designs available to choose from.

A. *Exhaust Muffler Grades*

1) *Industrial/Commercial*

- IL = 15 to 25 dBA
- Body/Pipe = 2 to 2.5

- Length/Pipe = 5 to 6.5

2) *Residential Grade*

- IL = 20 to 30 dBA
- Body/Pipe = 2 to 2.5
- Length/Pipe = 6 to 10

3) *Critical Grade*

- IL = 25 to 35 dBA
- Body/Pipe = 3
- Length/Pipe = 8 to 10

4) *Super Critical Grade:*

- IL = 35 to 45 dBA
- Body/Pipe = 3
- Length/Pipe = 10 to 16

IL= Insertion Loss, i.e., the level of sound reduction after attaching the muffler .The super-critical grade muffler generally represents the "top of the line" for reactive mufflers. Fig. 1 below shows a 3-chamber critical grade muffler. It achieves its "super-critical" status primarily from its length, as much as 16 x pipe diameters.

Fig. 1 shows the approximate insertion loss as a function of frequency for the various grades of mufflers. All values are approximate since no muffler has repeatable IL performance from engine to engine. It can be noted that the IL performance of the absorptive silencer is the best in the frequency region where reactive mufflers start to deteriorate.

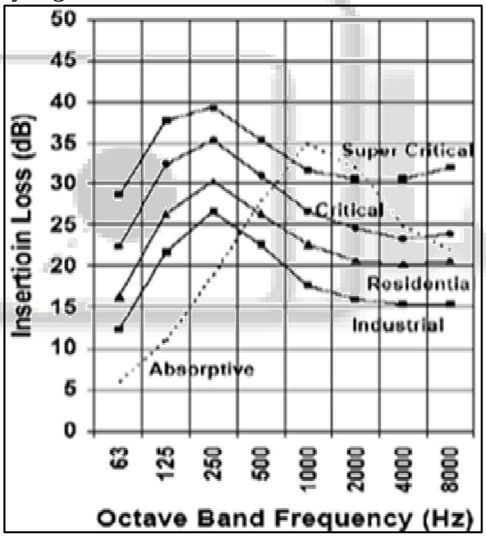

Fig. 1: Graph of Insertion Loss v/s Octave band Frequency

III. Design Calculations

For the experiment, an existing petrol engine has been used. Calculations are done on the basis of data collected from the engine; Specifications of the engine available for testing are as follows:

Make	Crompton Greaves
Model	IK-35
Bore 'diameter * Sroke	35 mm * 35mm
Capacity	34 cc
Power output	1.2 BHP at 5500 rpm
Torque	2.72 N-m @ 5000 rpm
Dry weight	4.3 kg
Cooling	Air Cooled engine
Lubrication	Mist –via petrol

Table 1: Specifications of Engine

1) Sound characteristics (Without silencer)

- Rpm of the engine= 5500
- Load Sound level
- Without any load 9.2 kg 104.5 dbA
- 50% load 15 kg 106.5dbA
- 100% load 24 kg 107dbA

2) Sound analysis with frequency analyzer (to obtain the dominating frequency)

Two dominating frequencies, the low level and the high level have been obtained. These are:

- Frequency Level Frequency (Hz)
- Low 270

High 40000

3) Diameter of exhaust pipe of engine/inlet pipe of muffler

The Exhaust Pipe diameter: 1.0 inch (25.4 mm)----this is in accordance to the standard mounting flange on the engine exhaust.

4) The theoretical exhaust noise frequency range

From various experiments is has been found that the theoretical exhaust noise frequency is 200-500Hz.

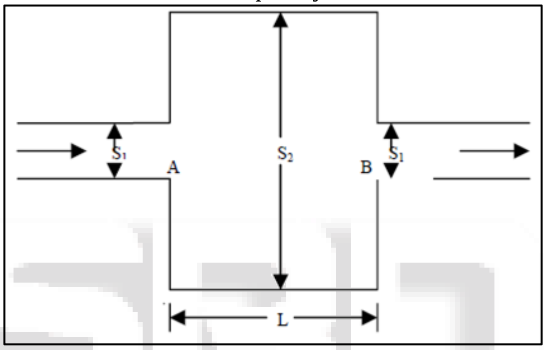

Fig. 2: Schematic of a Muffler Showing Various Dimensions

A. *Reflective Part Design*

S1 = Exhaust pipe diameter = 1.0 inch

The dimensions to determine are that of the chamber length L and the body diameter S2.

To determine L, three methods have been used. They are as follows:

1) *First Method used to Determine L*

Maximum attenuation occurs when L = $n\lambda/4$……(1)

where, λ = wavelength of sound (m or ft)

n = 1, 3, 5, …….(odd integers)

Since λ is related to frequency by the speed of sound, one can say that the peak attenuation occurs at frequencies which correspond to a chamber length.

The length for the engine exhaust specifications length is within the range of minimum 4.9 inches to maximum of 17.7 inches….as maximum conditions as never achieved because engine is always operated under load…hence length of the muffler smaller section is considered to be 5 inches and length of the overall section can be considered to be 17.7 inches or 450 mm.

2) *Range of chamber length considering the temperature of exhaust gas*

Another factor which must be considered in expansion chamber design is the effect of high temperature of exhaust gases. This factor can easily be included in the design by using the following equation:

$$0.5(49.03\sqrt{°R})/2\pi f \le L \le 2.6(49.03\sqrt{°R})/2\pi f \quad (2)$$

where, $\sqrt{°R}$=absolute temperature of the exhaust gas f = frequency of sound (Hz)

Let the temperature of exhaust is assumed to be 300º F or 759.7º R

Putting this value in equation (2), one obtains,

$0.5(49.03\sqrt{759.7})/2\pi 270 \le L \le 2.6(49.03\sqrt{759.7})/ 2\pi 270$

(here, f =270Hz for low frequency reactive muffler)

$0.4 \text{ ft} \le L \le 2.04 \text{ ft}$

From the 1st method, L = 17.7 inch = 1.47 ft.

So the condition of $0.4 \text{ ft} \le 1.47 \le 2.04$ ft is satisfied

3) Other parts of Reactive Muffler Design

It has always been considered that the flow path diameter does not reduce at any point. Otherwise, there would be a possibility of back pressure. That is why, the following equation has been used to determine the diameter of the smaller pipes, which are at the outlet of the first two chambers.

$$\pi S1^2/4 = \pi d1^2/4 + \pi d2^2/4$$

where, d1 and d2 are smaller pipe diameters.

As both pipes are of the same diameter, one gets,d1 = d2 = 1.06 inch ≈ 1 inch.

Now, the total length L has been divided into three small chamber lengths L1, L2, and L3.

As the pressure is dropping from the first chamber to the next, we reduced the length slightly from the first to the third.

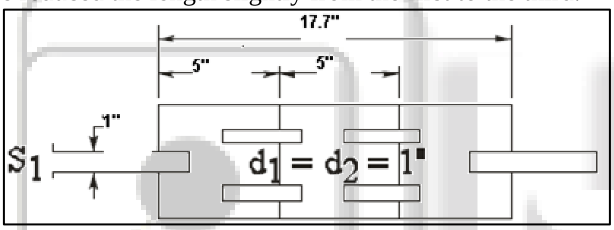

Fig. 3: A Simple Layout of Reactive Muffler with Dimensions

4) Tailpipe Design

According to equation (1), resonance occurs when $L = n\lambda/2$. So, for an economical construction, the value of n may be taken as 1. Then the tailpipe must be less than $\lambda/2$ ie, 3"

5) Resonator Design

Resonators are used to attenuate low frequency noise. The principle is to create an opposite phase waveform to nullify each other. The simplest way to produce a wave of opposite phase is to put a reflective obstacle at a distance of $n\lambda/4$, where n = 1, 3 other odd integers. A value of n = 1 has been used in the design. A damped resonator has been designed in form of thin membrane of brass as a result, the length of the resonator increases or decreases due to deflection under the action of shock wave. The range of length has been determined in the following way.

The velocity of sound increases 0.6m/sec with an increase in temperature of 1º C. The velocity of sound at 0º C is 332 m/sec. For the design purpose, the minimum temperature has been assumed to be 20º C and the maximum to be 300º C.

From previous section, the dominating frequency for low range is obtained to be 270 Hz. The range from 220 to330 Hz has been chosen here. A table has been constructed with various combinations to get the minimum and the maximum wavelengths, which can cover the above range.

Lmax and Lmin have been found to be 2.45 inch, i.e., and 3.525 inch, respectively.Thus the total resonator length becomes,Lres = Lmax + Lcyl + clearance for lubrication = 14.525 inch.

IV. EXPERIMENTAL SET-UP

Schematic of the test rig is as follows:

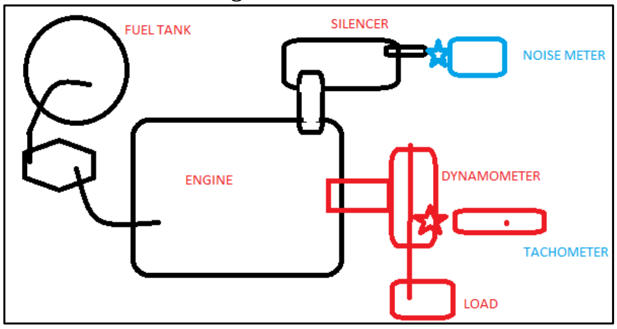

Fig. 4: Schematic of the Test Rig

Equipment used for trial is as follows:

A. Digital Tachometer

This is used to measure engine speed at various throttle openings.

Fig. 5: Digital Tachometer

B. Digital Noise Meter

This is used to measure noise at the exhaust of silencer at various throttle openings.

Fig. 6: Digital Noise Meter

Tests are done with application of load on the engine shaft and thus the following characteristics will be plotted.

1) Effect of change in load on engine output speed.
2) Effect of change in load on exhaust noise.
3) Effect of change in load on exhaust emission of % free carbon
4) Effect of Change in load on exhaust emission of %Carbon monoxide

Effect of change in load on exhaust emission of % unburnt hydrocarbons

V. RESULT & DISCUSSIONS

A. Observation Table with Conventional Silencer

% CO ---Percentage of Carbon monoxide in unit volume of exhaust gas---reference value below 4.5 % for 2/4 stroke engines in 2 wheeler vehicles

HC (n-Hexane equivalent ppm) ----reference value 9000 for 2/4 stroke engines in 2 wheeler vehicles.

LOAD (KG)	SPEED (RPM)	Noise (dBA)	%C0	HC
0	4330	108	0.98	460
0.5	4210	114.4	1.19	499
1	3950	127.4	1.41	539
1.5	3640	129	1.63	559
2.5	3930	132	1.81	579

Table 2: Observation Table with conventional silencer

B. Observation Table with Modified Silencer

%CO ---Percentage of Carbon monoxide in unit volume of exhaust gas---reference value below 4.5 % for 2/4 stroke engines in 2 wheeler vehicles

HC (n-Hexane equivalent ppm) ----reference value 9000 for 2/4 stroke engines in 2 wheeler vehicles.

LOAD (KG)	SPEED (RPM)	Noise (dBA)	%C0	HC
0	4380	87	0.86	340
0.5	4240	88.5	0.89	388
1	3970	91.6	1.04	425
1.5	3630	92.4	1.11	451
2.5	3450	96.3	1.21	456

Table 3: Observation Table with Modified Silencer

VI. CONCLUSION

A muffler should be designed to meet all the functional requirements namely minimum backpressure, be durable, produce desired sound, be cost effective. The interesting events of the design are designing a muffler which can reduce noise as well as pollution. From experiment it can be seen that noise is directly proportional to engine load. Depending on operating engine speed and maximum and minimum speeds individual muffler can be designed. In which resonating chamber reduces noise and twin chamber filter removes toxic gases. The minimum noise level obtained with fabricated muffler was found to be 87 dBa at no load condition. There will be many possible muffler design solutions are available for particular situation but design is proven itself only by its performance.

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