Design and Comparison of Mufflers Having Different Arrangements for Diesel Engine

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Abstract

IC engines are wide area of applications like automobile applications, marine applications, power generation, agricultural applications, light aircrafts etc. But major issues by using IC engine are to cause the air pollutions and noise pollutions. A noise pollution from the IC engine in a now a days is inherent issue. This noise can be reduced sufficiently by means of a well designed muffler. Muffler is the device used in an IC engine to control a noise within a limit and reduce a noise pollution. In this research work, six different arrangements of mufflers are designed and compared noise level for all mufflers. From comparison it is found that the dual exhaust type mufflers gets better reduction in noise compare to the single centre exhaust type and single side exhaust type mufflers. This dual exhaust type muffler provides reduction in noise by 29.56 db in case study of 5 HP diesel engine.

Keywords — *IC Engine, Noise Pollution, Exhaust Mufflers, Dual Exhaust Muffler.*

I. INTRODUCTION

An internal combustion engine is a one type of heat engine in which combustion takes place in a close cylinder; by combustion of fuel it produces a power. IC engines converts the chemical energy of fuel by means of combustion of fuel in a combustion chamber with help of air to the heat energy and then heat energy convert to the mechanical work or energy by means of piston, connecting rod and crank shaft. IC engines are wide area of applications like automobile applications, marine applications, power generation, agricultural applications, earthmoving applications, locomotive engines, mining equipments, generators, light aircrafts etc [17]. There are mainly two types (Petrol & Diesel) of IC engine mostly used in a most of all applications [17].

Main disadvantages of IC engines are described as: Low efficiency (around 30-40%) for producing power[17], High heat loss in IC engines, Vibration problem due to reciprocating parts in a IC engine, There is major pollution caused by the IC engine (1) Air pollution (2) Noise pollution. This research work mainly concern to reduce a noise pollution of IC engine.

Noise is defined as 'an undesirable sound' or 'an unwanted sound'. Sound is the pressure wave developed from the pulses of alternating high pressure and low pressure of air. In the IC engine, pressure wave generated when the exhaust valve is opens & closes repeatedly. Therefore high pressure of exhaust gases converted to low pressure that generates the pressure pulses, which produces a sound wave. Sound wave flows to exhaust pipe along exhaust gases. These pressure pulses that a noise produces from the engine. Without muffler gasoline engine produce exhaust noise in the range from 85 to 100 dB while an unmuffled diesel engine emits exhaust noise in the range from 100 to 125 dB [2]. Human ears can sense the sound of frequency range 20 Hz to 20 kHz. While the ear can sustain a noise up to 80-100 db, above 100 db noise creates pain and discomfort to human and also causes the loss of hearing[2]. There is a need of designing the proper element to reduce a noise from the IC engine and it is known as the muffler or silencer [12], [13]. Therefore in this research paper muffler design procedure is described briefly. Muffler design is the trial & error type design. Therefore muffler can be design by comparison of different arrangements. This research gives the detail design of mufflers different arrangements and their noise level comparisons.

Muffler is defined as a mechanical device used to deplete the noise generated by an internal combustion engine. A muffler not only reduces noise, but also diminishes vibrations. It was invented by "MILTON" and "REEVES" in 1896. There are main two types of muffler mostly used in an IC engine application: (1) Absorptive muffler (2) Reflective or Reactive muffler [2]. Many times combination of both mufflers is also used and it is known as combined muffler. This muffler having a very high capabilities to attenuate the more noise compare to the absorptive and reactive mufflers. Many other types of mufflers are also available in applications like, Baffles plate type, Resonance type, Wave cancellation type, Chambered type, Active noise cancellation type muffler etc[2]. But all are worked as same principle for either an absorptive type mufflers or reactive type mufflers.

II. MUFFLER DESIGN

Mufflers are important equipment of engine system and used in exhaust system to minimize noise caused by combustion process. Basic requirements of muffler design are Quiet and interchangeable, Good Performance, Compact Design & Light weight, Simple in maintenance and a Specific requirement of muffler design are Reduce the noise in given application, Replaceable, Doesn't increase back pressure, Easy Manufacturing & mounting, Cost of muffler etc.[6][4] There are mainly five design criteria considered for muffler design. The acoustic criterion related to the noise reduction. The geometrical criterion, related to the muffler shape and considerable volume for space availability. The mechanical criterion, related to the material selection for the muffler design. The aerodynamic criterion**,** related to the pressure drop calculation for engine exhaust gas at a given temperature and pressure. The economical criterion**,** related to the cost factor for making a muffler. [10] For muffler design parameters should be considered like; Size of muffler (Length and Diameter), Diameter of Inlet and outlet pipe, Perforated Holes on the pipe, Number of reactive chambers, Length of absorptive chamber, Number of inlets and outlet pipes, Required insertion loss, Cost of muffler etc[10].

Muffler can design by the following steps; main design includes length and diameter of muffler and length of inner chambers of muffler.

A. Design of Muffler Length and Muffler Diameter

Table 1: ASHRAE Standard Grades for Muffler Design[2],[14]

Grades / Parameters	Industr-ial (or) Comm-rcial	Reside-ntial	Critical	Super Critical
Insertion Loss(DBA)	15 - 25	20 - 30	25 - 35	35 - 45
Body Dia. Of Muffler / Exhaust pipe Dia.	2 - 2.5	2 - 2.5	3	3
Length Of Muffler / Exhaust pipe Dia.	5 - 6.5	6 - 10	8 - 10	10 - 16

There are different standard mufflers grades provided by ASHRAE (American society of heating, refrigerating and air-conditioning engineers) technical committee 2.6 for the designing of mufflers for engines [14]. They provide four different grades (as shown in Table 1) for design a muffler diameter and muffler length with require insertion loss. By these muffler grades, muffler length and muffler diameter can design for optimum reduction in a noise level.

Insertion Loss (I.L.):- A muffler performance and muffler noise reduction capability is generally defined in terms of insertion loss. It is defined as the difference between level of sound without and with muffler attached.

Here select critical grade for design the length and diameter of muffler by considering insertion loss, space condition and cost parameters. Also from literature survey found that the critical grade is best suitable grade for the designing of diesel engine mufflers.

So critical grade having [14],

I.L. = 25 to 35 dBA;

Body Dia. of Muffler (D_m) / Exhaust Pipe Dia.(d_e) = 3;

Length of Muffler (L_m) / Exhaust Pipe Dia. (d_e) = 8-10.

Therefore;

D_m= 3 x d_e = 3 x 40 = 120 mm (here d_e = 40 mm) &

L_m= 8 x d_e to 10 x d_e = 8 x 40 to 10 x 40 = 320 mm to 400 mm

B. Muffler Inner Reactive Chamber Design

For inner chambers design, it is requires to measure frequency at which peak noise will be noted from the engine exhaust. Muffler inside reactive chamber length design by using destructive phenomenon of sound wave and this was done by sound level meter attached with frequency filter to get the value of frequencies at highest engine exhaust noise from which it can found the length of inner reactive chamber. Here Bruel & Kjaer type 2235 precision sound level meter used (Fig. 1) for measurement of noise from engine exhaust and Bruel & Kjaer type 1625 frequency filter (Fig. 1) used to measurement of frequency range at peak noise from engine [7].

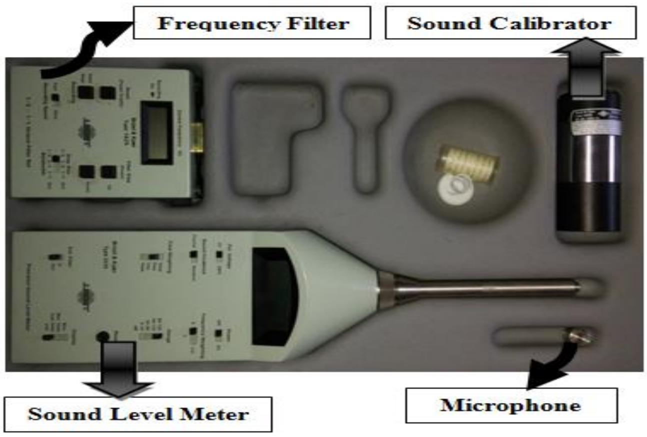


Figure 1: Sound Level Meter

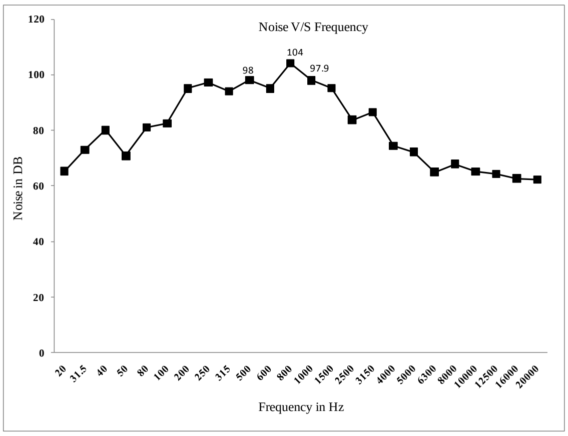
From this experiment, it is found the reading of frequencies range at different noise as shown in table 2. From this, graph of frequency v/s noise (fig.2) can plot and found the three frequencies at which peak noises are recorded. From that length of muffler's reactive chamber will be calculated. From experiment found that the highest peak noise occurs at middle range of frequencies, so select three frequency 500 Hz, 800 Hz & 1000 Hz (as shown in fig. 2) at which peak noise from engine exhaust is noted.

Muffler inside reactive chamber length can design by using destructive phenomenon of sound wave. Destructive phenomenon says that the destruction of sound wave occurs (maximum reduction of noise) when length of chamber is one fourth of the wavelength [1], [3], [5], [7].

Table 2: Experimental Reading of Frequencies at Different Noise Level

Noise Frequency in Hz	Noise level in DB
20	65.3
31.5	73
40	80
50	70.8
80	81
100	82.5
200	95
250	97.1
315	94
500	98
600	95
800	104
1000	97.9
1500	95.2
2500	83.7
3150	86.5
4000	74.4
5000	72.2
6300	65
8000	67.9
10000	65.2
12500	64.2
16000	62.7
20000	62.3

Figure 2: Noise V/S Frequency Graph



Mathematically; maximum noise reduction occurs when chamber length is,

$L = n \times \lambda/4$ .... (1)

The relation between the frequency and wavelength is given by;

$C = f \times \lambda$ .... (2)

At STP speed of sound is C = 332.4 m/s.

Consider the three peak noise frequency 500Hz, 800Hz and 1000Hz for designing (from experiment),

So, from equation (2),

- Wavelength for 500 Hz frequency is given by,

$\lambda_1 = C/f_1 = 330/500 = 0.660$ m = 660 mm

Similarly, wavelength for frequencies 800 Hz and 1000 Hz;

$\lambda_2 = C/f_2 = 330/800 = 0.4125$ m = 412.5 mm,

$\lambda_3 = C/f_3 = 330/1000 = 0.33$ m = 330 mm.

Consider above three calculated wavelength of sound wave,

From equation (1),

- Length of chamber for wavelength λ_1;

$L_1 = \lambda_1/4 = 660/4 = 165$ mm

Similarly for wavelengths λ_2, λ_3;

$L_2 = \lambda_2/4 = 103.125 \cong 103$ mm,

$L_3 = \lambda_3/4 = 82.41 \cong 82$ mm

- So, Length of reactive chamber is;

$L_{mr1} = L_1 + L_2 = 268$ mm (for 2 reactive chamber)

$L_{mr2} = L_1 + L_2 + L_3 = 350$ mm (for 3 reactive chamber)

C. Design of Inner pipes in Muffler

It has been considered that the flow path diameter does not reduce at any point. If flow path diameter reduces then there is possibility to produce a backpressure on the exhaust gases and reduces the engine efficiency. So it improves the proper flow of the exhaust gases to the outlet of the muffler and improves efficiency of engine [1], [3], [7], [9].

Therefore mathematically described as,

$A_e = A_1 + A_2$

$\pi d_e^2/4 = \pi d_1^2/4 + \pi d_2^2/4$

$40^2 = d_1^2 + d_2^2$

$2 d_1^2 = 40^2$ (Take, $d_1 = d_2$ = muffler inner pipe diameter)

$d_1 = \sqrt{800}$

$d_1 = d_2 = 28.28$ mm $\cong 28$ mm

D. Design of Inlet and Outlet Pipes Diameter

From the literature survey found out that the diameter of inlet and outlet pipes are taken same as the diameter of engine exhaust pipe and length of inlet and outlet pipes are decide as per the engine space requirements.

Therefore, $D_{in} = D_{out} = 40$ mm

E. Design of Absorptive Part of Muffler

Length of absorptive part of muffler is finding out by subtracting the muffler's reactive part length from the total length of muffler.

Therefore length of absorptive muffler is given by,

$L_{ma1} = L_m - L_1 - L_2 = 400 – 268 = 132$mm (for 3 chamber)

$L_{ma2} = L_m - L_1 - L_2 - L_3 = 400 - 350 = 50mm$ (for 4 chamber)

Here, three arrangement of muffler have a length of L_{ma1} and other three arrangement of muffler have a length of L_{ma2}.

III. MUFFLER'S DIFFERENT ARRANGEMENTS

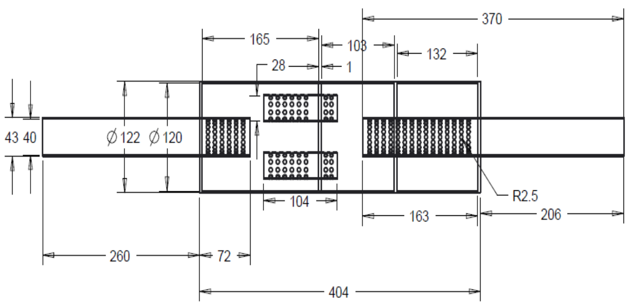
Design inputs arrived from theory of acoustics used to muffler design [5], [6], [7],

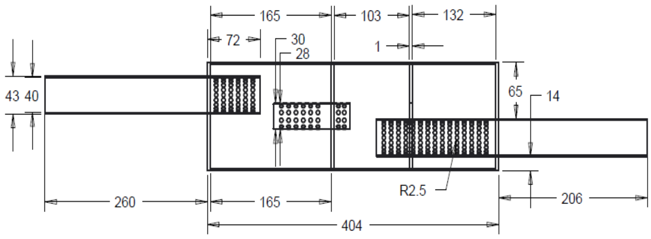
- Extended inlet and outlet in the muffler will be minimum 55 to 75 mm for better attenuation results.
- From benchmark and theory three expansions chamber good for noise target for reactive muffler.
- Noise reduction increases with increase in a perforation hole sizes.
- Inlet and outlet are introduced 180 deg reversal to increase the acoustic performance.
- Combined muffler gives better reduction in noise compare to single reactive or absorptive muffler.

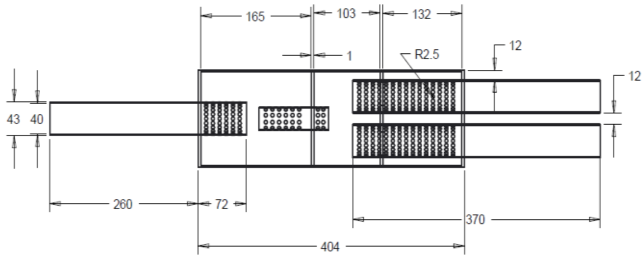
By considering the above acoustics phenomenon and literature review muffler can design by different arrangements. Muffler can design by different arrangements like single exhaust, dual or twin exhaust, centre inlet – centre outlet, side inlet – side outlet, changing the numbers of chambers, changing length of absorptive part of muffler, changing the diameter of perforation holes etc. In this work different six arrangements of mufflers are designed. All mufflers are combined type mufflers i.e. reactive and absorptive type muffler.

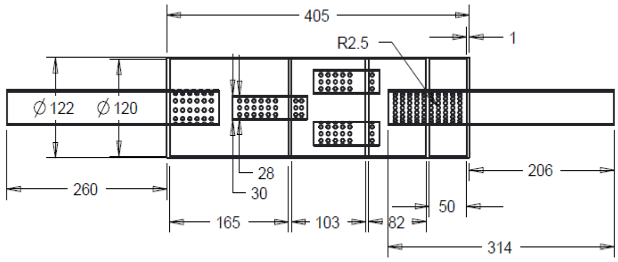
Following six alternative arrangements are manufactured and compared noise level from engine exhaust for all.

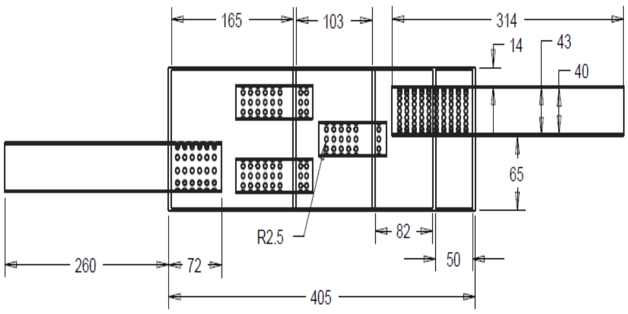
1. Muffler with 3-chamber, single exhaust
2. Muffler with 3-chamber, single exhaust at side inlet and side outlet
3. Muffler with 3-chamber, dual exhaust
4. Muffler with 4-chamber, single exhaust
5. Muffler with 4-chamber, single exhaust at side inlet and side outlet
6. Muffler with 4-chamber, dual exhaust











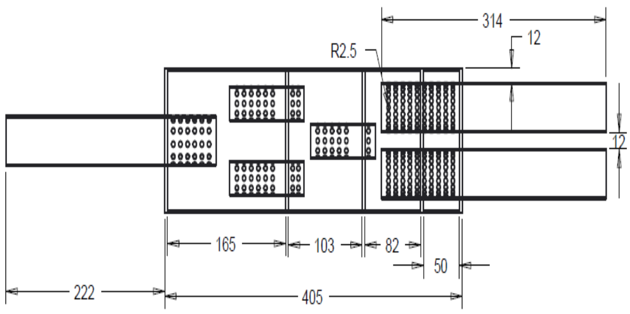


Figure 3: Creo 2.0 - Drawings of all Different Muffler Arrangements

In first three arrangement of muffler having a total three chamber, in which two chambers are reactive chamber and one is absorptive chamber. Reactive chamber reduces a noise of lower frequencies 500 Hz and 800 Hz respectively while absorptive chamber reduces a noise of higher frequencies above 1000Hz. In last three arrangement of muffler having a total four chamber, in which three chambers are reactive chamber and one is absorptive chamber. Reactive chamber reduces a noise of lower frequencies 500 Hz, 800 Hz and 1000 Hz respectively while absorptive chamber reduces a noise of higher frequencies above 1000Hz. In this three arrangement length of absorptive part of muffler is reduced (132 mm to 50 mm) compare to first three arrangements.

Here different three type of exhaust system in muffler's arrangement are taken; like single centre outlet exhaust, single side outlet exhaust and dual exhaust. Figure - 3 shows the Creo Parametric 2.0 drawings (2-D) of all six type of arrangement. These all arrangement of mufflers are manufacture and tested experimentally to measurement of noise level for each muffler and select best muffler for given case study of 5 HP cooper diesel engine.

IV. MANUFACTURING OF MUFFLER

Muffler must be sustaining high temperature and it has also high corrosiveness. So muffler material must have high boiling point and high corrosion resistance. Therefore generally material of all type of mufflers taken as mild steel or stainless steel, also mild steel coated with aluminium that increases the corrosion resistivity of material. From literature review and manual of muffler making companies found that the materials used for exhaust piping and reactive mufflers mainly of ferrous alloys; Aluminium alloys are sometimes used as a coating on ferrous alloys to impart additional corrosion resistance. (Exhaust products guide, Donaldson Filtration Solution) [8], [14], [15], [4]. Generally muffler made from Sheet Steel; the aluminized mild carbon steel and stainless steel (with or without coating of aluminium).

Absorptive mufflers contain sound-absorbing material such as fibreglass or wire wool [8]. This type of material absorbed the pressure energy in form of the sound wave and this pressure energy converted into the heat energy due to the friction in material therefore it results the reduction of noise level. Absorptive material performance depends on their sound absorptive co-coefficient.

Figure 4: Manufactured all Six Arrangement of Muffler

Mufflers manufacturing processes contains mainly cutting operations, bending and press rolling operations, grinding operations, drilling operations, punching operations and welding operation. First of all cutting operation will carry out on the mild steel sheet as per the required dimensions of muffler then sheet will bended and pass out the press rolling process to give the round shape of muffler. After that inner pipes and inlet – outlet pipes are welded on muffler body as per the calculated design dimensions.

Figure 5: Punching(Marking) at Inlet Pipes of Muffler

Figure - 4 show the all six manufactured mufflers with different arrangements. As shown in Figure – 5 punching operation carry out on inlet pipes with number one to six to easily identification of the different arrangement of mufflers with their design drawings. Now these all mufflers are to be tested experimentally on engine to identify best muffler which reduce more noise and noise level comparison of all arrangement of mufflers are measured.

V. EXPERIMENT AND RESULT

This experiment performs for measurement of noise level from engine exhaust without muffler and with all arrangement mufflers. These experiments are useful to measurement of insertion loss of muffler. Noise measurement was done with the sound level meter as per the ANSI technique of noise measurement to get the optimum result of noise level.

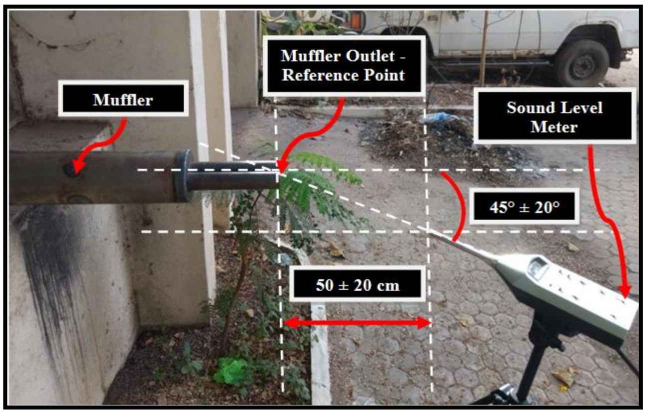


Figure 6: Experimental Setup for Measurement of Noise Level from Engine

Experimental setup for noise measurement is shown in figure 5. As per the ANSI standard the microphone of sound level meter must be placed behind the exhaust pipe at a distance of 50 ± 20 cm from the reference point of the exhaust pipe and at the same height as the reference point ±2 cm. Sound level meter place on an imaginary line at a 45° angle ±20° angle with respect to the longitudinal axis of the exhaust pipe of the engine (figure - 5) [11], [16].

Table 3: Noise Level from Engine - without Muffler & with all Six Mufflers at Different Loads

Different Loads(kg)	Noise Level in DB (decibel) from Different Loading Conditions						
	No Muffler	With all Six Arrangements of Muffler					
		1	2	3	4	5	6
0 kg	109.5	82.3	83.3	81	79	81.4	**77.1**
2.26 kg (5 lb)	111.6	86.2	87.7	84.5	81.6	84.5	**81.1**
4.53 kg (10 lb)	115.5	94.5	94.8	90.3	90.4	91.5	**87.8**
6.80 kg (15 lb)	118.1	97.1	98.9	94.6	92.3	93.1	**90.1**
9.07 kg (20 lb)	121.9	99.4	101	97.2	95.1	95.9	**92.7**

Table 4: Insertion Loss of all Six Arrangement of Mufflers

Different Loads(kg)	I.L. in DB(Decibel) for all Muffler Arrangement at Different Loading Condition					
	1	2	3	4	5	6
0	27.2	26.2	28.5	30.5	28.1	32.4
2.26 kg (5 lb)	25.4	23.9	27.1	30	27.1	30.5
4.53 kg (10 lb)	21	20.7	25.2	25.1	24	27.7
6.80 kg (15 lb)	21	19.2	23.5	25.8	25	28
9.07 kg (20 lb)	22.5	21.1	24.7	26.8	26	29.2

Muffler Different Arrangements	Average I.L. in DB (Noise Reduction)
1	23.42
2	22.22
3	25.80
4	27.64
5	26.04
6	29.56

Table 5: Average Insertion Loss of all Arrangements of Muffler

Table 3 and Table 4 show the noise level and Insertion Loss at different loads without muffler and with all six mufflers from engine exhaust respectively. Now insertion loss calculated for each muffler, high insertion loss value indicates the good muffler.
Insertion loss calculated by following equation;
I.L. (DB) = Noise level before muffler attached – Noise level after muffler attached
Below table 5 shows the average Insertion loss for all loads.

From this experiment it is found that the lowest noise level recorded for muffler arrangement number six, which have four chambers and dual exhaust. Now figure number – 6 show the graph of the insertion loss comparison of all six arrangements of mufflers.

Figure – 7 shows the graph (line chart) of insertion loss for all mufflers at different loads; from this found that lowest I.L. noted for 2nd arrangement of muffler denoted as a Muffler 2 and highest I.L. noted for 6th arrangement of muffler denoted as a Muffler 6.

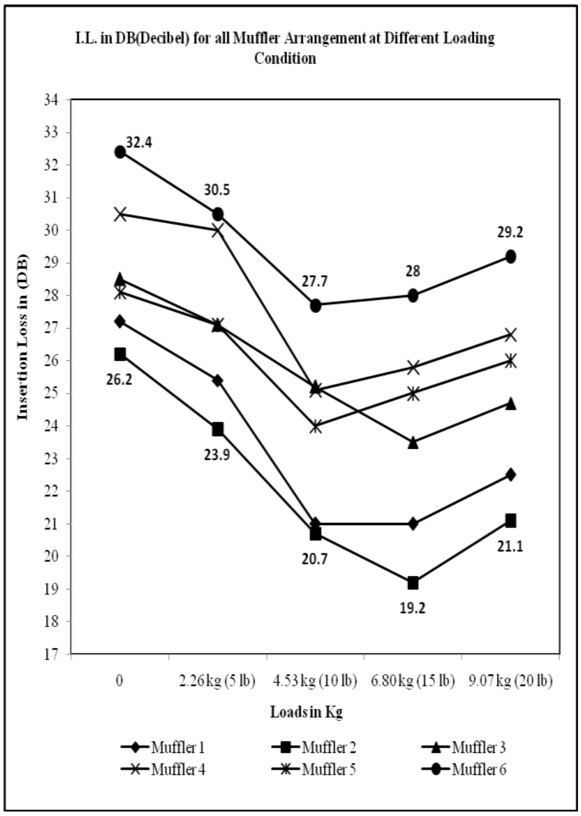


Figure 7: Graph of Insertion Loss for all Mufflers at Different Loads

Muffler arrangement 4th and muffler arrangement 1st has a second highest I.L. (denoted as Muffler 4) & second lowest I.L. (denoted as Muffler 1) respectively.

Muffler arrangement 3rd and 5th has equal I.L. for 5 lb load; 3rd arrangement has more I.L. than 5th arrangement for load 0 lb & 10 lb; and 3rd arrangement has lower I.L. than 5th arrangement for 15 lb & 20 lb load. But average I.L. of 5th arrangement is more than 3rd arrangement.

Above experiment result shows that the high insertion loss found in a 6th muffler arrangement. After that insertion loss are reduces in order of 4th, 5th, 3rd, 1st, 2nd arrangement of muffler. We observed that insertion loss higher in four chamber muffler compared to three chamber muffler, dual exhaust muffler reduced high level of noise compared to single exhaust muffler, single centre exhaust type muffler having high insertion loss compared to single side exhaust type muffler. Therefore result shows that if numbers of chambers are increases in muffler then it gives high reduction in noise and double exhaust muffler gives high I.L. compare to the single exhaust muffler and single side outlet exhaust type mufflers having a lowest noise reduction.

VI. CONCLUSIONS

From this research it is conclude that the muffler design is the trial and error type design; there will be many possible muffler design solutions for a particular situation. Muffler can be design by the different arrangements like single exhaust, dual or twin exhaust, centre inlet – centre outlet, side inlet – side outlet, changing the numbers of chambers, changing length of absorptive part of muffler, changing the diameter of perforation holes etc. The muffler can be designed by various methods to achieve good performance. Combined muffler gives better reduction in noise compare to the single reactive muffler or absorptive muffler. From the experimental comparison it is found the highest noise reduction (29.56 db) noted for 6th arrangement of muffler which have 4 – chamber and dual exhaust so that it is conclude that the high number of chamber and dual exhaust type muffler reduces more noise compare to less number of chamber and single exhaust type muffler because it has low resistance to exhaust the gases to atmosphere (due to the dual outlet – more outlet passage area). Side single exhaust type muffler having lowest noise reduction (26.04 db - 5th muffler & 22.22 db – 2nd muffler) because travelling and resistance of exhaust gases are more in this type of mufflers. Centre single exhaust type muffler's noise reduction (27.64 db - 4th muffler & 23.42 db – 1st muffler) is in middle range of dual exhaust & side single exhaust type mufflers. Noise reduction in three chamber type mufflers is low compare to the four chamber type mufflers, therefore if number of chamber increases in muffler it gives better reduction in noise.

VII. NOMENCLATURE

- B.P. = Brake Power of Engine (HP)
- DB or DBA = Unit of Noise Level – Decibel
- I.L. = Insertion Loss(db)
- D_m = Diameter of Muffler Chamber (m)
- L_m = Total length of Muffler (m)
- d_e = Diameter of Exhaust Pipe(m)
- C = Sound Velocity of air
- f = Frequency of Sound Wave (Hz)
- λ = Wavelength of the Sound (m)
- L_1 = Length of First Chamber of Muffler (m)
- L_2 = Length of Second Chamber of Muffler (m)
- L_3 = Length of Third Chamber of Muffler (m)
- L_{mr} = Length of Reactive Chamber of Muffler (m)
- d_1 = Diameter of Inner Pipe 1(m)
- d_2 = Diameter of Inner Pipe 2(m)
- N = Maximum Engine Speed (rpm)
- D_{in} = Diameter of Muffler Inlet Pipe (m)
- D_{out} = Diameter of Muffler Outlet Pipe (m)
- L_{ma} = Length of Absorptive Chamber of Muffler (m)

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