

# **A Study on Effectiveness of Muffler on a Two Wheeler Noise**

*A Dissertation submitted*  
in partial fulfilment of the requirements  
for the degree of

**Master of Engineering**  
in  
**Production Engineering**

by

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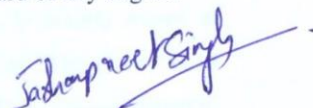
**DEPARTMENT OF MECHANICAL ENGINEERING**  
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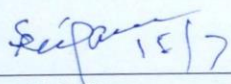
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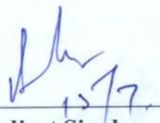
I hereby declare that the research work entitled "A study on effectiveness of muffler on a two wheeler noise" is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering in Production Engineering** at **Thapar University, Patiala** under the supervision of **Dr. S.P. Nigam (Visiting Professor)** and **Mr. Daljeet Singh (Assistant Professor)**, Mechanical Engineering Department, Thapar University, Patiala during July, 2013 to July, 2015. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

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
  
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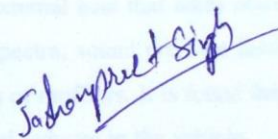
  
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At Thapar University, I learned many things like the research work is mainly aimed at enabling the student to apply their theoretical knowledge to practical as "The theory is to know how and practical is to do how" and to appreciate the limitation of knowledge gained in the class room to practical situation and to appreciate the importance of discipline, punctuality, team work, sense of responsibility, money, value of time, dignity of labor.

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# Abstract

The major contribution of the traffic noise, towards overall noise pollution, is a well-known established fact. Traffic noise from highways creates problems for surrounding areas, especially when there are high traffic volumes and high speeds. Noise pollution has hazardous effects on human health like Effects in work efficiency, loss of hearing ability. It may cause headache and psychological strain. Generally today's main source of noise is traffic noise, out of which 70% is due to traffic noise. In order to minimize the noise it is necessary to study two-wheeler noise. In two-wheeler noise the main source of noise is exhaust noise. To reduce exhaust noise different types of mufflers are used. In this study Royal Enfield Bullet motorcycle (350 cc) was used to measure the noise of two-wheeler. In this different types of mufflers were studied out of which two were reflective type (M1 and M2), one was free flow (M3) and one was hybrid type (M4). This M4 type muffler was prepared by using technique of reflective type and absorptive type muffler a new hybrid type muffler M4 is modified from their existing design by introducing 1 cm thick glass wool because of its absorptive nature and it also controls the external heat that takes place on the outer surface of the muffler. Sound power, frequency spectra, sound pressure level and insertion loss are measured without and with different types of mufflers. It is found that due to this hybrid modification there is 2 dB (approx.) noise level reduced in the vehicle.

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# Nomenclature

A	A – Weighted Level
a	Length in m for sound power
b	Breath in m for sound power
c	height in m for sound power
dB	Decibel
Hz	Hertz
$L_{eq}$	Equivalent Sound Pressure Level
$L_{10}$	10 percentile Sound Pressure Level
$L_{50}$	Median value of sound level
$L_{90}$	90 percentile exceeded sound level
$L_p$	Average sound pressure level in dB (A)
$L_w$	Acoustic power in dB (A) (ref. $10^{-12}W$ )
$L_{max.}$	Maximum Sound Pressure Level
$L_{min}$	Minimum Sound Pressure Level
$L_i$	Sound Intensity Level
Pa	Pascal
S	Hypothetical surface area
SPL	Sound Pressure Level
$S_0$	Reference area

# Chapter 1

## Introduction

---

### 1.1 Introduction

Noise means “unwanted sound.” In our present world, noise is the major environmental developing problem. A long hearing exposure to intense sound may cause permanent damage to hearing.

Main source of noise are as following

1. Industrial noise
2. Traffic noise
3. Community noise

Out of the above parameters, traffic noise is major source of noise. Traffic noise is produced by the numbers of vehicle moving on the road. Near about 70% of the noise is produced by the traffic noise. [1]

**Sound:** Sound is the physical disturbance in a medium (in air, solid or liquid) that is sensed by the human ear. The medium in which sound waves travels must have mass and density. Sound waves will not travel in vacuum. In air sound waves are caused by the variations in pressure above and below the static value of atmospheric pressure (value of atmospheric pressure is  $10^5$  Pascal's)

**Decibel:** Decibel is the ratio of the logarithmic value of two quantities. It has no units. Decibel is defined by expression as

$$10\log_{10} (P/P_0)^2 \quad (1.1)$$

Where P is the sound pressure amplitude of the measured sound

$P_0$  is a reference pressure i.e.  $20\mu\text{Pa}$

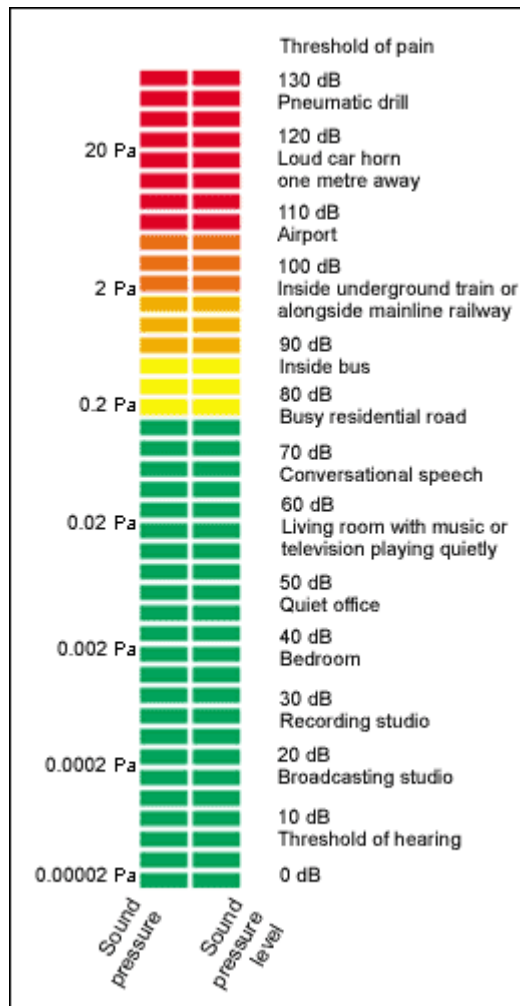


Fig1.1 Environmental condition at different  
Sound pressure level [W.1]

## 1.2 Sound Sources

1. Point source
2. Line source
3. Plane source

### 1.2.1 Point Source

A sound source can be considered as a point source, if its dimensions are small in relation to the distance to the receiver and it emits equal amount of energy in all direction. This type of sound is obtained from industrial plants, individual road vehicles, aircrafts etc. The sound pressure level decrease 6 dB as the distance between the source and the receiver is doubled.

### 1.2.2 Line Source

Line source can be considered as a continuous emission, such as from a pipe carrying a turbulent flow, or a large number of point sources so close together that their emission may be considered as a continuous line. Like a railway train, closely spaced vehicles are treated as line source. The pressure decreases 3dB as the distance from the line source is doubled.

### 1.2.3 Plane Source

When two sources emit sound energy, they both will contribute to the sound pressure level a distance away from the sources. If they radiate same amount of energy and distance between the points of measurement to the sources is the same, then the level will be increased by 3dB as compared with the level created by one source alone. These types of sources are very rare and only found in duct system.

## 1.3 Physical Property of Sound

### 1.3.1 Sound Power

The rate of transfer of energy from the source to its surrounding air molecules is known as sound power. A unit of sound power is W (watt). The audible range of sound power is  $10^{-9}$  W to 1000 W.  $10^{-9}$  W is the lowest level from where the listener heard the source from the closed distance and 1000 w is the highest value at which damage of hear will cause.

### 1.3.2 Sound Intensity

When there is sound produced from the source, it will create certain sound intensity (I) at a distance away from the source. The intensity of sound is measured from the amount of power through a certain area at this distance. The value of sound intensity can be calculated after measurement of the sound pressure level, knowing the area over which measurement takes place. The relationship between the sound pressure (p), intensity (I) and sound power(P) can be written as

$$p^2 \propto I \propto P \quad (1.1)$$

### 1.3.3 Sound Pressure Level

Sound pressure level is defined as the logarithmic ratio of decibel (dB)

$$L_p = 20 \log_{10} p/p_0 \quad (1.2)$$

Where  $P$  is the sound pressure measured

$P_0$  is the reference sound pressure i.e.  $20\mu\text{Pa}$  (threshold of hearing)

## **1.4 Characteristics of Sound**

### **1.4.1 Background Noise**

Background noise is all the other noises other than the sound which is being measured. The electrical noise produced by the measuring instrument is also the background noise.

### **1.4.2 Correction for Background Noise**

Measurement of sound sources should be taken in the absence of background noise, if this is not possible, the background noise level may be reduced by using some absorptive screens, windscreen or by temporary barriers.

To measure the sound, following method is valid only if the background noise is steady and consistent from measurement to measurement.

1. Measure the sound pressure level of the combined source noise and the background noise.
2. Measure the background noise by turning off the main sound source.
3. Calculate the difference between these two values.
4. Read the correct value from the figure 1.2.
5. Subtract the correct value from the combined sound pressure level measured in step1 and obtain the correct sound pressure level. [2]

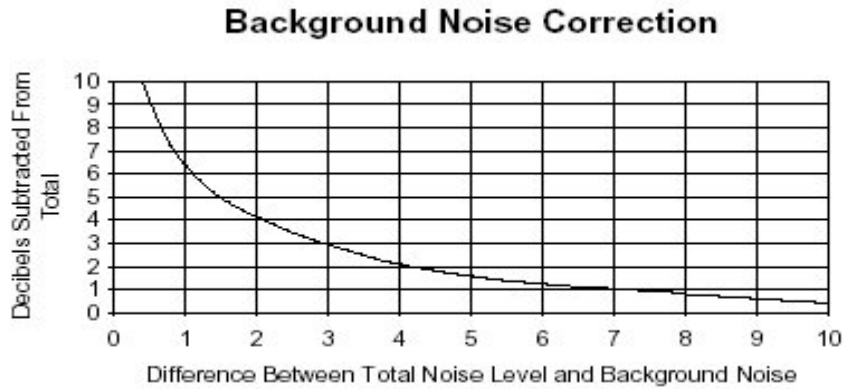


Fig 1.2 Correction for background noise [W.2]

### 1.4.3 Weighting Curves

The non-linear response of the human ear is taken care by the introduction of weighting filters, to carry out measurements, which correlate well with the response of the human ear. A-weighting curve is the most commonly used because it gives best correlation between the measured value and the aggravation and effect of the sound signal. A-weighting curves follow 40 phons curves where B and C weighting curves follow 70-100 phons curves. The D-weighting curves follow a contour of perceived noise measurement and it is mainly used in aircraft noise measurement.

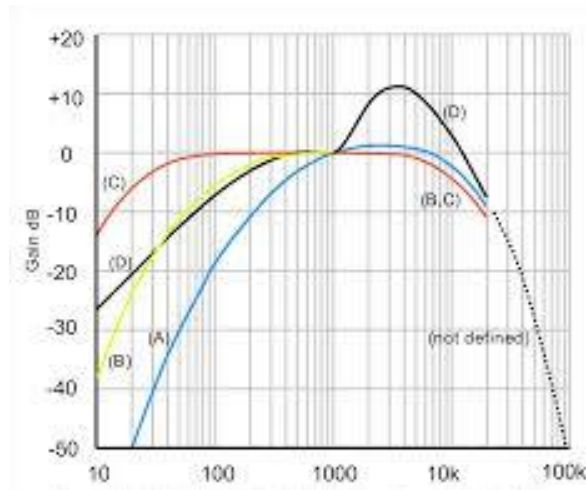


Fig1.3 weighting curves [W.3]

#### 1.4.4 Equivalent Continuous Sound Level ( $L_{eq}$ )

$L_{eq}$  is the energy mean of the averaged noise level in the measured period.

$$L_{eq} = 10 \log_{10} \left[ \frac{1}{T} \int_0^T \left( \frac{P_A(t)}{p_0} \right)^2 dt \right] \quad (1.3)$$

Where  $P_A(t)$  is the A-weighted instantaneous sound pressure.

T is the total measurement time.

$P_0$  is the reference sound pressure of 20 $\mu$ Pa.

#### 1.4.5 1-1 octave and 1-3 octave bands

In the microphone electrical signal is amplified and processed which send output in the form of graphical display or wave. The range of frequency which filters attenuation is called filter bandwidth. The analysers most commonly used for acoustical analyser have a normal band width which is proportional to, and constant percentage of, the mid band frequency and are the octave band analyser, which have nominal band of one octave and the one-third octave band analyser, which has a nominal band width of one-third octave.[1]

### 1.5 Harmful Effect of Noise on Human Beings

1. Affects speech communication.
2. Affects work efficiency.
3. Causes psychological strain.
4. May cause mental fatigue.
5. May cause temporary/permanent threshold shift
6. May increase in cholesterol level.
7. Upset the chemical balance in the human body.
8. Induces loss of hearing ability.
9. May causes headache.

### 1.6 Useful Application of Noise

**1.6.1 Study of Heart Beats:** Noise produced by the human heart is very useful for diagnose the health of human being.

**1.6.2 Masking Effects:** Sometimes, it is necessary that nobody should hear the conversation between the two persons. For example in doctors room, doctor does not want that anybody hears his conversation with the patient, so he uses masking effect by putting some noisy exhaust fan which makes noise outside the room.

## 1.7 Noise Measuring Instrument

Many types of instruments are available to measure the sound level. The most widely used is the “sound level meter” instrument to measure the frequency-weighted and time-average sound pressure level. Sound level meter are light in weight, small in size.



Fig1.4 Sound Level Meter [W.4]

### 1.7.1 Elements of Sound Level Meter

**Microphone** the function of microphone is to convert the variation in pressure of sound waves into time-varying electric signals.

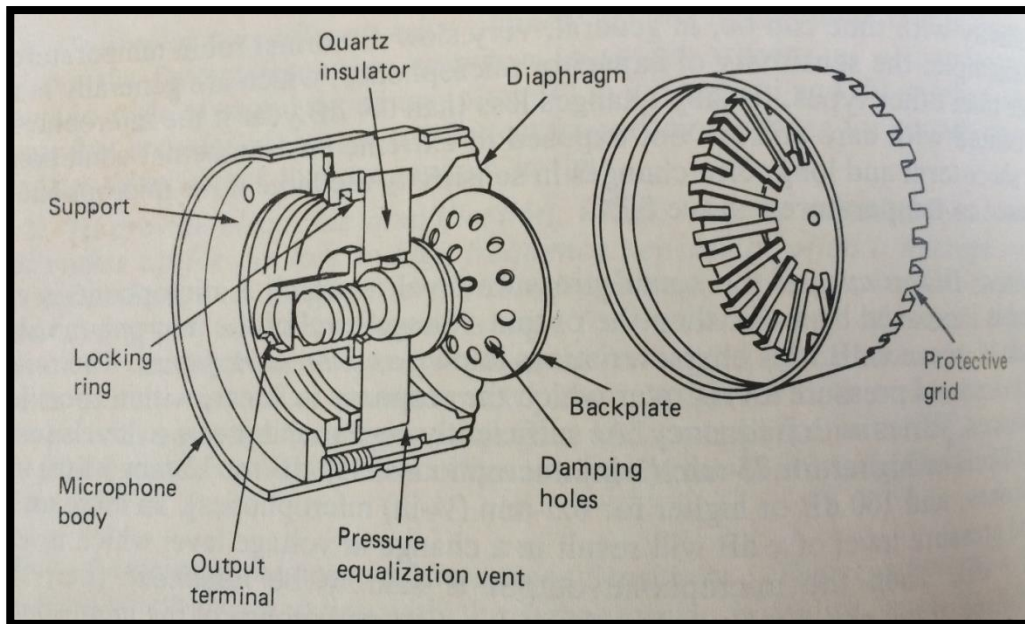


Fig1.5 cut-section view of microphone [34]

**Different types of microphones are:**

1. Capacitor ( condenser ) microphone
2. Pre-polarized microphone
3. Piezoelectric microphone

**Amplifier:** It amplifies the signal from the microphone sufficiently to permit measurement

**Rectifier:** It rectifies the signal from analog into digital form.

**1.7.2 Steps to Measure the Noise**

**Calibration:** Before taking measurement, firstly check the sensitivity of the measuring instrument.

**Use of windscreen when taking outdoor measurement**

1. To reduce the effect of wind on measurement wind screen is used.
2. Wind screen is open-cell plastic foam of porous ball or some porous material used to cover microphone.
3. Noise generated by the wind can be reduced by fitting wind screen.[1]

**1.8 Importance of Sound power**

Sound power is the noise radiated by a source is independent of both location and the environmental condition. The sound power level of a source does not change in value from

one physical location to another, provided the source is operated in the same manner, while the sound pressure level reduced by a piece of equipment varies both with the distance between equipment and the point of measurement and with the environment in which equipment is placed. [3]

## 1.9 Measurement of Sound Power Level

### 1.9.1 Sound Power Level Measurement with Sound Pressure Level

Following are the some step to measure the sound power level of noise source.

1. Surround the noise source with hypothetical surface of area  $S$  ( either hemi-spherical or rectangular parallelepiped )
2. Calculate the area of hypothetical surface, if it is hemi-sphere,  $S$  is given by  $2\pi r^2$ , where 'r' is the hemi-spherical radius.
3. If the area of hypothetical surface is rectangular, then  $S$  is given by  $ab+2(ac+bc)$   
Where a, b, c are its length, width, height.
4. Measure the sound pressure level at designated point on the hypothetical surface.
5. Calculate the average  $L_p$  of the sound pressure level measured in step 4.
6. Finally calculate the sound power level from the following equation.

$$L_w = L_p + 10 \log_{10} (S/S_0) \quad (1.4)$$

Where  $S_0$  is the reference area and  $S$  is hypothetical surface area

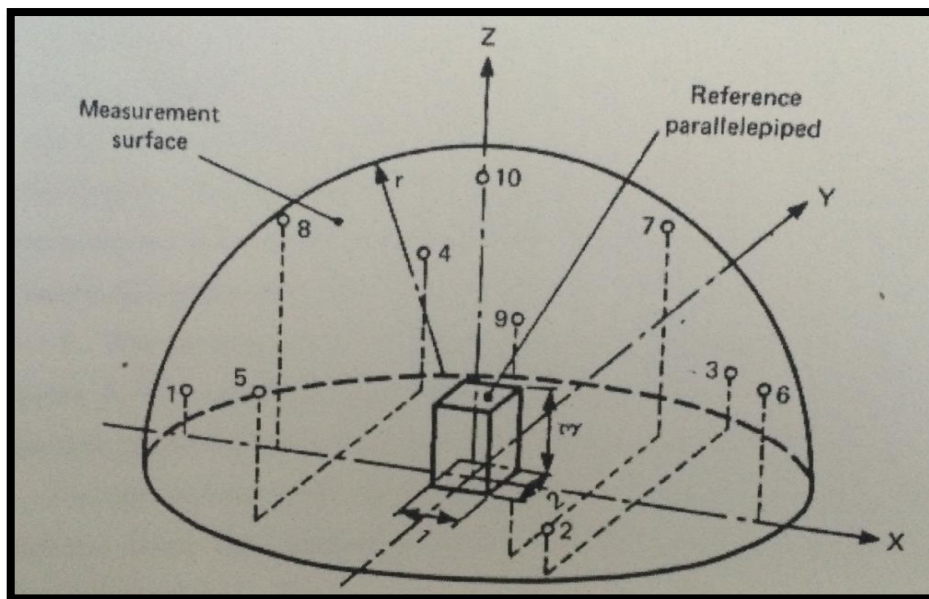


Fig1.6 Graphical representation of microphone position on an imaginary hemispherical surface surrounding a source[35]

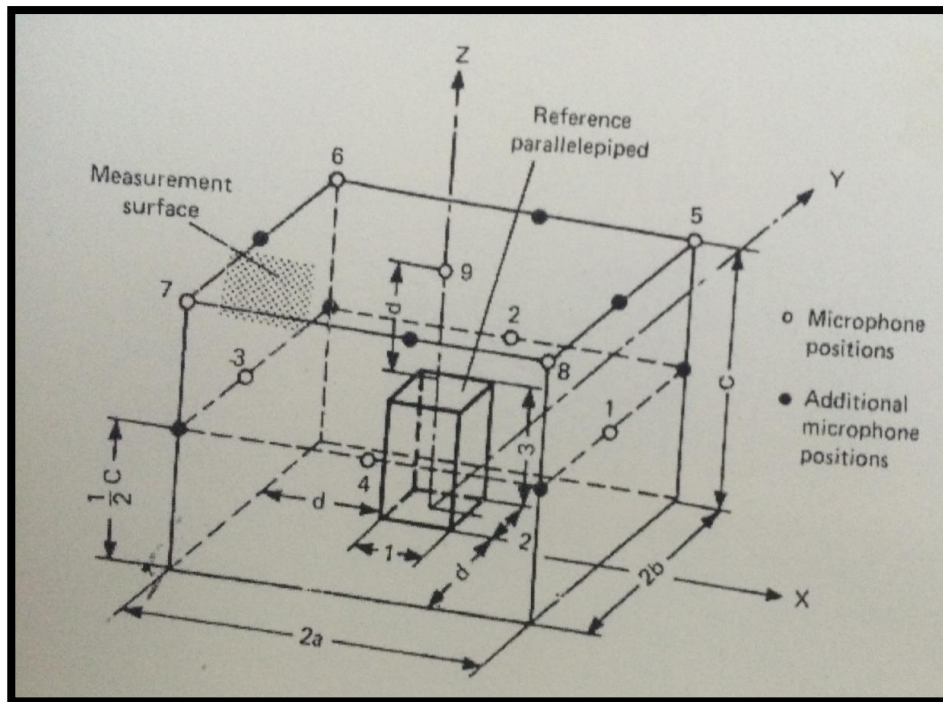


Fig 1.7 Array of microphone positions on an imaginary parallelepiped surface surrounding a source whose sound power is to be measured [35]

### 1.8.2 Additional aspects of measurement correspond to the steps in above procedure:-

1. For small source whose largest dimension is significantly less than the one meter (3 ft). It is more convenient to use hemisphere than rectangular parallelepiped as a hypothetical measurement surface for a large rectangular source the rectangular parallelepiped surface is generally preferred.
2. The radius of hypothetical hemisphere should be equal to or greater than twice the major source of dimension and not less than 1m for the rectangular parallelepiped, the measurement 'd' the perpendicular distance between the source and the measurement surface has a preferred value of 1m.
3. For hemispherical the designed point of the microphone locations are shown in figure 1.6 and for parallelepiped the designed point of the microphone locations are shown in figure 1.7. The sound pressure level at designated point is measured with A-weighted in one octave or in one-third octave bands.
4. The average sound pressure level over the measurement surface,  $L_p$  is calculated from the measured sound pressure level  $L_{pi}$ , after correction for background noise.

# Chapter-2

## Two-Wheeler Noise

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Two-wheelers are becoming increasingly prevalent as a means of transportation. Because of the variety of vehicles intended uses, noise characteristics vary quite widely for this class of vehicles. Two-wheelers cover a wide range of power to weight ratio so that even a typical operation may call for a wide range of available power output.

### 2.1 Sources of Two Wheeler Noise

In most motor vehicles the engine structure, intake exhaust, transmission, brakes, aerodynamic flow and tyres are all important contributors, under various conditions, to total vehicle noise. The major sources of noise in the two-wheeler are engine noise which is discussed below. [4]

#### 2.1.1 Engine Noise

An engine is a mechanical device that generates certain form of output from a given input. An engine whose purpose is to generate kinetic energy output from a fuel source is called a prime mover, alternatively, a motor is a device which generates kinetic energy from a pre-processed fuel such as electricity, a flow of hydraulic fluid or compressed air. Engine noise is produced by combustion of fuel in the cylinder.

#### 2.1.2 Combustion Noise

Combustion noise is produced because of unsteady combustion of fluid and is of two types turbulent combustion and periodic combustion oscillation. The turbulent combustion noise or combustion roar has no specific frequency but is composed of broad-band frequency spectrum. This noise is amplified if the flame is enclosed with the system resonance frequencies dominating. The requirement for reduction of this noise tends to be opposition to chemical energy into oscillatory in the gas flow to the combustion region. The mechanism is such that the pressure waves generated are so phased to the velocity fluctuation. The noise spectrum involves one specific frequency and its harmonics and that frequency is related to the resonant modes of the combustion chamber. Some of the possible cures are:

1. Modification of combustion chamber geometry
2. Change of air-fuel ratio, burner type etc.

### 3. Change of burning rate

It has been noted that combustion roar in reciprocating engines which has frequency of the firing rate is not related to the combustion noise, but is due to the gross fluctuation in the flow rate produced by periodic action.

#### **2.1.3 Exhaust Noise**

An exhaust noise is generally the noise generated by the combustion of fuel in the cylinder of the engine. The entire system carries burnt gases from the engine and contains one or more exhaust pipes. This produces some amount of noise because of these pressurized gases. In almost all two-wheeler motorcycles the exhaust system is visible.

#### **2.1.4 Mechanical Noise**

Mechanical noise is the noise which is generated by various impacts between the engine parts. This noise source is more important in the higher frequency range rather than in lower frequency where combustion noise is important. There are lots of moving parts like Gears, valves, rocker arms, piston and cylinder liner. Some are as follow:

**Engine Clicking Noise** is the noise created by the engine when there is low oil pressure, excessive valve lash, or worn or damaged parts. A clicking or tapping noise in the engine is generally caused by the tappet or worn or damaged parts. This may be caused by low oil pressure, excessive valve lash or damaged parts.

**Collapsed Lifter Noise** is generated by worn, leaky or dirty in the lifters is the main reasons of valve-train noise. If there is dirt in the oil or in oil delivery in the lifters (plugged oil galley or low oil pressure) the lifters won't pump up to take up the normal relaxed in the valve-train.

**Valve Lashes Noise** is the noise when large space between the tip of the rocker arms and valve stems cause increase in valve-train noise level and probably cause enhanced wear of both parts.

**Damaged Engine Parts Noise** is the excessive wear on end of the rocker arms, cam followers and valve stems can built-up the valve lash, which may increase in noise level.

**Rapping or Deep Knocking Engine Noise** is the deep rapping noise from the engine is usually "Rod Knock" which may be caused by the extreme bearing wear or damage. The noise level increases if the rod bearing are worn or free sufficient to make a dull, hammering noise.

**Piston Slap Noise** is generated by the sudden impact of the piston to the cylinder wall is considered to be predominant due to the higher amount of energy released. In the

compression stroke, the connecting rod pushes the piston upwards overcoming the gas force. The force acting on the piston has a lateral component and the piston slides upwards on the minor thrust side of the cylinder wall. Thus, as the crank pin passes through the cylinder centre line. The piston to accelerate through the clearance and slap against the cylinder centre direction, causing the piston to accelerate through the clearance and slap against per revolution, but the major impact occurs at T.D.C before the power stroke .these simple models do not take into account others factors which may affect the piston motion such as:

1. Piston pin offset.
2. Rocking motion of piston.
3. Friction motion of piston
4. Frictions at piston pin as well as piston outer surface.
5. Pressure distribution around piston due to the squeezing of oil film.
6. Compliance of cylinder liner wall.

### **2.1.5 Bearing Noise**

Crank shaft bearing are permanently changed when reassembling an engine because they are wear element. Heat, pressure, chemical attack, abrasion and loss of lubrication can all donate to weakening of the bearing. This may cause increase in noise level. Some of the factors that cause bearing are as follow:

**Dirt** causes premature bearing failure. When dirt or other abrasives particles are positioned between the crankshaft journals and bearing, it damaged the soft bearing material. The softer material, the greater the embed ability, which may cause the wearing in the size of component and the thickness of the bearing material.

**Heat** is additional reasons that enhance bearing wear and may lead to failure if the bearings become hot in an adequate amount. Bearing are mainly cooled by oil flow between the bearing and journal. Everything that reduces the flow of oil not only increases the temperatures but also increases the risk of scoring or wiping the bearing

**Misalignment** is another condition that can cause bearing wear. If any part in the engine is misaligned or moved from their place by which may cause block or damaged the internal functioning of the engine.

**Disassembly** may cause of premature bearing failure. Common factors are

1. Installing the wrong sized bearing.

2. Installing the wrong half of a slip bearing as an upper.
3. Getting too much or not enough crush.
4. Dirt behind the bearing shell.

**Corrosion** can play also an important role in bearing failure and produce noise. Corrosion results in foreign particles on the surface of the crankshaft and attack the bearing pitting in the bearing surfaces. If the oil is not changed at their required time which may cause bearing in engine particles.

**Spark knock** is a knocking, rattling or pinging noise that might be sensed when the engine is accelerating or working under load. Spark knock means the fuel is detonating. Some of the factors that cause spark knocking are

1. EGR (Exhaust Gas Re-circulation) valve not working
2. Compression ratio too high
3. Engine overheating
4. Performance of fuel used

### **2.1.6 Tyre Noise**

Tyre noise is the noise produced by the tyre when vehicle is in moving condition. With the increase in the speed of the vehicle noise will also increase

Parameters which influencing the tyre noise.

#### **Effect of Speed**

With increase of speed sound level rise, but slightly different rates.

#### **Effect of Wet Road Surfaces**

With the significant increase in sound level for the wet surface condition.

#### **Effect of Load**

Increase in load results in an increase in the noise rates.

#### **Effect of Temperature**

There is no significant change in the overall sound level with changes in temperature over the range of 25-125 F.

### **2.1.7 Gear Noise**

The main sources on which gear noise depend

**Inaccurate Tooth form and spacing** can cause gear wear which creates gear noise.

**Stress** between the gears can cause the gear by which gear noise occur.

**Air pocketing** means when air entraps between the gear teeth's which may cause gear noise.

**Oil pocketing** means when the oil entraps between the gear teeth's which cause the gear noise.

**Friction** between the gears also causes the gear noise. With the increase in the friction, their also increase the noise rates.

**Installation** problem can also cause the gear noise like misalignment of gear, improper meshing of the gear, manufacturing fault etc. [4]

### **2.1.8 Mufflers**

It is a device for reducing the noise produced by the engine. In internal combustion engine the exhaust gases flow out through the muffler. In muffler there is a resonating chamber which is tuned to minimize the exhaust noise.

#### **Requirement for an Engine Exhaust Muffler**

1. Adequate insertion loss.
2. Backpressure needs to be kept to a minimum.
3. Large mufflers having fitting problem, supporting problem and excessive cost price.
4. Material of muffler must be corrosion resistive.
5. Spark-arresting capacity is required.
6. The sound produced by the source will be smooth.
7. Breakout noise from muffler should be minimum.

#### **Types of Muffler**

1. Reflective type
2. Absorptive type
3. Hybrid type
4. Free flow type

**Reflective type Muffler:** Reflective mufflers are those type of muffler in which different cross-sectional area is designed at different location to minimize the noise and fluctuation in the noise.

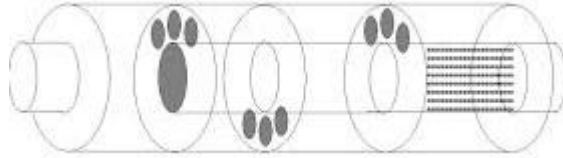


Fig 2.1 Reflective type muffler [W.5]

**Absorptive type Muffler:** In this type of muffler some absorbing material (mineral wool, fibre glass, sintered metal composites, white wool) is used which absorb the noise and minimize the sound. The important tools of absorptive muffler are absorber modelling and numerical computation.

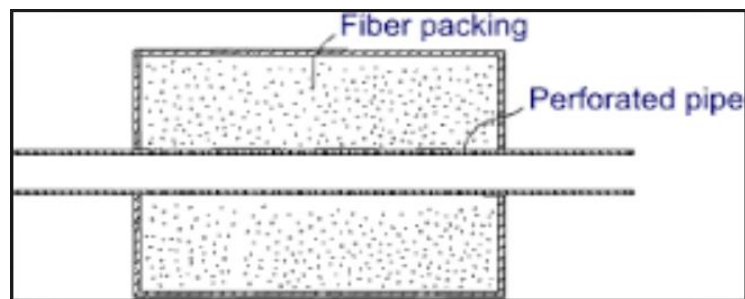


Fig 2.2 Absorptive type muffler [W.6]

**Hybrid type Muffler:** Hybrid mufflers are those type of muffler in which both reflective and absorptive technique combinedly used. This type of muffler is best design to reduce the noise. [5]



Fig 2.3 Hybrid type muffler [W.7]

**Free flow muffler:** This type of muffler is simply a pipe with resonating chamber. There is no any reflective or absorptive material used in this type of muffler.

# CHAPTER-3

## Literature Review

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A lot of research work has been carried out throughout the world to investigate and analyse the effectiveness of muffler on a two wheeler noise. A brief review of literature is being presented here. This chapter covers the extensive literature review of research work which has been done by different researchers.

**Tandon et al. [6]** studied the two wheeler engine and their noise control. The major noise produced by the engine of a two-wheeler has been studied. In order to find the source of high noise, Intensity spectra and sound intensity of the engine were obtained which leads to results that the high noise was primarily created by the cylinder of the engine. The main causes found in noise creation are Piston slap of the engine and nature of cylinder head fins.

**B. Sudhakara [7]** paper is about the urban transportation in India. Basically there are two types of transportation i.e. road and rail in which they consume 90% of the total transportation energy. This paper is representing an overview of Mumbai's transportation system, which includes a well-developed rail and road network. It is found that at an annual growing rate of 4% personal vehicles are on the road which rapidly increase the petrol and diesel consumption at around 4% annually.

**Sathyarayanan. Y and Munjal M. L [8]** show a new hybrid approach towards the prediction of noise radiation from engine exhaust. In this paper, cylindrical void is studied in the time domain to analyse the exhaust mass flux. In this method, nonlinear propagation in the exhaust pipe is neglected and free expansion is supposed at the radiation and at the exhaust pipe. Results were quite well with time domain approach and the frequency domain approach.

**Campbell Steele [9]** predicted a sound pressure level at the road side of a single vehicle. The various models used were based on various factors like constant speed experiments, as purposes of speed and at zero acceleration, the predicted level was expressed. Models were not planned to forecast single vehicle levels but to calculate the equivalent sound pressure level  $L_{eq}$  over a selected period. Different commonly used models had been reviewed here

are designed to meet the requirements of roadway engineers and they do not meet the requirements of other users of traffic noise models. The Ideal model is proposed to supply the deficiency.

**Filho et al.[10]** Analysed the effects of traffic composition on road noise. In this paper effect of traffic composition in typical Brazilian roads was analysed. The aim of this survey was to discover the features of the noise are linked to road traffic mass and composition. In this survey total 149 measurements were made on three roads and their equivalent level  $Leq$  were measured. After the survey they concluded that the most of the reasons for the noise is due to heavy vehicles and few factors like use of horns, with or without apparent reason, driving fast, accelerates in traffic jams or while waiting for a green traffic light.

**Bilawchuk. S and Fyfe K, R [11]** made a comparison and implementation of the several numerical methods used for measuring transmission loss. Different types of methods were used to predict and design the exhaust Results shows that the FEM method is better for this kind of application and was easier to usage than the 4-pole method.

**Barbieri et al. [12]** measured the acoustic performance of the two mufflers. To predict the bi spectrum and kurtosis approaches. By using two microphone method, the experimental data were obtained and numerical values was calculated by finite element method. By comparing these results it was found that there were deviations between mathematical and experimental data.

**Potente et al. [13]** discussed about the muffler design and general principles. They discussed about 2 type of muffler i.e. the absorptive and reflective type of muffler. The absorptive type muffler is tested on a formula SAE vehicle. It is observed that the noise of vehicle is 128 dB (A) when there is no muffler is placed and when absorptive muffler is placed the measurement is 110 dB (A). So they calculated the insertion loss of this muffler is to be  $(128-110) = 18\text{dB (A)}$  analysed.

**Lee C. M and Wang Y. S [14]** predict the acoustical properties of multi-layered noise control materials in standing wave duct systems.in this five type of noise control material was used. Experimental results show the acoustical property of multi-layered system might be obtained by adding more layer or by sub suiting layers with higher quality material treatment.

**Cho et. al. [15]** studied the effects of various kinds of vehicles category on pavement surface types on noise had been tested at the Korea Highway, south Korea in 2005-06, in which measurement is made at a field of nine surface sections of concrete and Portland cement

concrete pavements with eleven vehicles. The sound power levels were measured combined vehicle noise and tire/pavement interaction. Noise of various vehicles were measured based on the novel close proximity and pass-by methods. The various features of the sound power levels were calculated permitting to surface type, type of vehicles, and their speed. Various tests give us the result that the sound power levels of vehicles are varyingly affected by vehicle speed and the situation of the road surface.

**Asensio et al. [16]** describes the method to calculate directivity index and sound power level based on field measurement made at Madrid- Barajas Airport (Spain). Sound power levels have been measured in 1-1 and 1-3 octave bands. Results shows that the noise level is vary from 125 to 133 dB (A).

**Banerjee et al. [17]** evaluate the factors that considerably effect the sound pressure level on road traffic noise level ( $L_{eq}$ ) and obtain artificial models for the industrial town of Asansol, India. The observations show that  $L_{eq}$  values are mainly effected by the hourly traffic volume. Measurements were taken at 35 locations, spread over the city. The traffic volume in most locations varied between the mean values during the day time was  $2176 \pm 1190$  vehicles/h. During the night the mean count was  $1190 \pm 742$  vehicles/h. Conclusion was made that the  $L_{eq}$  values for the day time and night is

- $L_{eq-d} = 79.084$  dB
- $L_{eq-n} = 58.374$  dB

**Chen S. R and Too G. P.j [18]** studied about the simulations and experiments for hybrid noise control system. Purpose of this paper is to explore the effects of sound elimination in a cylindrical duct. In this experiment, a combined adaptive algorithm is adopted. Experimental results show the hybrid system had the advantages over the traditional muffler.

**Yasuda et al. [19]** studied the tail pipe from a commercial automotive muffler experimentally and numerically under wide open throttle acceleration. Firstly engine was accelerated from 1000 to 6000 rpm in 30 sec. Results shows that simulation is in good arrangement with investigational work. By using one dimensional CFD model, a simplified model was projected for the optimization design to meet the demand of time to market.

**Zhao et al. [20]** study of non-straight roads was measured with novel traffic-noise prediction method. In this study non-straight road like interchanges and flyovers were studied by noise–

prediction methods. These non-straight roads are divided into several small road sections and traffic-noise levels of each section are then calculated individually. The proposed model and the FHWA model were applied to predict the traffic noise of non-straight roads for a comparison. And they concluded that there is minor difference. The observation tells us that the accuracy of the approximate model depends on the length of small road section. The length of the small road section was proposed for less than or equal to half of the distance between the receiver and the sound source.

**Yang Li et al. [21]** measured a quantitative measurement of pass-by noise emitted by vehicles running at high speeds. This technique has attained by high precision calculation and quantitatively measures the sound pressure at the sound source and detects the location of the main sound source. And this method also validated by the model investigations and the measurement trials with known moving speakers. The successfully identification by this method are, tyre noise, exhaust noise, engine noise and wind noise of the vehicle moving at different engine speed . Real work condition test results for cars moving at speed from 57 to 117 km/h have demonstrated that the low frequency noise of the car is mainly caused by the engine while the high frequency noises are mainly the tire and wind noise. After all the measurements, they conclude that the tire and wind noise will grow stronger when the car's speed increases.

**Lima et al. [22]** studied the reactive silencers by shape and parametric optimization techniques. This parametric optimization is studied to evaluate the suitable size of inlet and outlet ducts in order to improve the acoustic performance of the muffler in a specific frequency range. Transmission loss was measured at different types of shapes of ducts. Results showed the optimization efficiency of the muffler ducts acting in a specific frequency range with gains up to 20 dB with respect to silencers without shape optimization.

**Pierrette et al. [23]** studied based on the survey and a total annoyance model comparison of Noise annoyance from industrial and road traffic combined noises. its aim is to study annoyance due to combined industrial and road traffic noises and it include survey among residents living near an industrial site and surrounded by two roads. This survey also takes place at small towns and locations where the various industrial and road traffic emits continuous and steady noises. The results show that industrial and road traffic noises did not disturb listening activities or conversations. Indeed, 99% of the respondents reported that listening activities were not disturbed at all by the industrial noise.

**Yee Ho et al. [24]** goal of this paper is to measure the effects of road and tyre wear on tyre/road noise. In this the effect of road surface and tyre material on the sound level shows the results that the tyre/road noise measured on different types of road surface increase the noise by 1.2– 1.5 dB(A) The noise by 0.6 dB(A) increases by the tyre hardness. Depending upon the road surface material, the tyre/road noise level increased by 0.6–2 dB(A). The slightest effect of the test tyre aging on road noise amount is 0.6 dB(A) per year.

**Jena et al. [25]** analysed the motor bike piston-bore fault identification from engine noise level. Analysing engine faults by a skilled auto-mechanic just by hearing the noise level from a faulty vehicle has been struggled with a robust instrumentation technique. The main purpose is to find the piston-bore defect by analysing the engine noise

**Singh et al. [26]** studied the outcome of rubber dampers on engine's NVH (Noise–Vibration–Harshness) and thermal performance. This paper provides a systematic technique to study the effect of rubber dampers and a way to quantify these dampers from the engines. The fins used for heat transfer vibrate at various frequencies due to which unwanted noise is generated. In order to reduce the fins amplitude Rubber dampers are used and thus decrease the emitted noise from the fin faces .An experiment done without and with different size of rubber damper with different shapes. Results shows that rubber dampers support in reducing engine noise level at higher engine speeds, but rubber dampers also increase engine temperature by about 10%.

**Wen et al. [27]** analysed the reduction of noise and vibration in an underwater vehicle. By using periodic structure theory, vibration and noise emission from an underwater vehicle due to excitation from propeller forces is examined. By using modular approach, a model of the propeller system is built and studies the propeller, shaft, thrust bearing, isolation assembly. The dynamic properties and isolation performances of vehicle are compared and analysed. Results show that the vibration and noise emission are greatly mitigated in the stop bands. By altering the design of its periodic isolators and its united structures, the defeat in the vibration and noise emission can be developed effectively.

**Kim et al. [28]** optimized the lower arm of a vehicle suspension system. This study analysed characteristics of road noise level by using vehicle tests at 200–230 Hz frequency range This is the most important frequency for road noise reduction. By using transfer path analysis, Vibration sources in the vehicle suspension system were identified. PQRS (Progressive Quadratic Response Surface Method) is used for design optimization problems. Results

shows that the road noise level are reduced by accomplished by applying the optimally planned lower arm of the vehicle suspension system to an actual practise.

**Braun et al. [29]** paper is about the Noise basis features in the ISO 362 vehicle pass-by noise test objective to limit vehicle noise emissions. The test is applied by allowing to the international standard ISO 362. A constant speed test is conducted to determine ta pass- by value. By which the manufacturers and suppliers must check the vehicle noise source structures during the design stage of the vehicle. Major sources source of noise in any vehicle are engine noise, intake system, exhaust system, tyre/road system.

**Renterghem et al. [30]** measured the light vehicle noise and minimized it by using hedges. This study examines the structural noise of the vehicle so as to qualify approximation of its relative importance. By using in-situ method to measure the noise shielding by hedges. Insertion loss is measured, three controlled pass-by experiments is made by using a reference microphone at close distance, and by using point source transmission loss are measured. Results show that the higher noise drops are found to be related with an increased ground effect.

**Yasuda et al.[31]** studied the automobile muffler with acoustic characteristic of low-pass – filter. In this paper acoustic performances of the muffler were studied theoretically and experimentally. The interconnecting holes enabled the proposed muffler to have acoustic attenuation performance of helmholtz resonator. It was found that graph peak and tough is related to the resonance and anti- resonance frequency of the muffler acoustic element.

**Kori N. M [32]** focused on the fall in exhaust noise emitted by diesel engine silencer. In this “fiberfrax S96” material with high noise absorption factor and high temperature resistance is used in indica DLS car silencer. Results are showed that the noise was reduced around 4 to 5 dB(A). Noise was with indica DLS silencer was average 53 dB(A), where using fiberfrax S96 it was reduced and the result showed that 48 dB(A).

**Venkataraman.B and Raj Gokul [33]** observed the passive noise control techniques are employed to control the exhaust noises. In this paper both absorption and reflective mufflers were experimentally used to calculate sound transmission loss. Observations shows that reactive muffler has better transmission loss in lower and mid-range frequencies and deteriorates in higher frequency, where absorptive muffler reduces below 600 Hz also the glass wool packing density of  $120 \text{ kg/m}^2$  produces highest sound transmission loss.

The above literature survey gave an idea to take a problem on noise. Noise measurement has been done in different fields like Traffic noise, city noise, automobiles etc. The aim is to study the effectiveness of different types of mufflers on a two wheeler noise by measuring the acoustic power, sound pressure level and insertion loss.

# Chapter 4

## Basics of Muffler

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### 4.1 Introduction

Muffler is a device which usually equipped with internal combustion engines to minimize the acoustic pulse generated by the combustion process. In the engine cylinder, a very high intensity pressure waves are generated, which transmit along the exhaust pipe and emit from the exhaust pipe termination. Pulse repeats at the firing frequency of the engine.

$$f = \text{engine R.P.M} * \text{No. of cylinders} / 120 \text{ Hz} \quad (\text{for four stroke engine})$$

The majority of the pulse energy lies between the 0-600 Hz frequencies ranges. Exhaust muffler are designed to reduce sound levels at these frequencies. Sound waves transmitting along a pipe can be decreased by using muffler.

### 4.2 Basic requirement of muffler Design

1. Adequate insertion loss
2. Selection of size
3. Back Pressure
4. Cost and Weight

#### 4.2.1 Adequate insertion loss (IL)

An effective muffler will reduce the sound pressure of the noise source to the required pressure of the noise to the required level at the end of the tail pipe or receiver. A muffler performance is generally defined in terms of insertion loss or transmission loss.

**Insertion loss** of a sound attenuator, sound barrier, or other element designed to provide sound reduction in a specified frequency band, the decrease in sound power level measured at the location of the receiver when this element is inserted in the transmission path between the sound source and the receiver

**Transmission loss** is defined as the difference between the average sound pressure level occurrences at the entry to the muffler to that of the transmitted by the muffler. The muffler

designer must determine the required insertion loss so that a suitable type of muffler can be designed for the automotive application. [1]

#### **4.2.2 Selection of size**

To ensure the best specific design principles, a proper selection and sizing of the muffler is essential. The selection of the correct type of engine exhaust muffler is determined by

- Type of engine.
- End use of the engine.
- Degree of silencing required.
- The silencer size selected must satisfy the specified volume of exhaust gas flow keeping the back pressure within the specified limit.
- The available space has a great influence on the size and type of muffler may be used.

#### **4.2.2 Back pressure**

It is the additional static pressure exerted by the muffler on the engine through the restriction on the flow of exhaust gases. Back pressure should be kept to a minimum to avoid power losses and for better performance. Absorptive type muffler creates less backpressure as compared to other types of mufflers.

#### **4.2.3 Cost and weight**

Usually the larger the muffler is, the more its weight and more its cost. To manufacture effectively supporting a muffler is always a design issue and the larger a muffler is the difficult it is to support. A muffler's mounting system not only needs to support the mufflers weight but also needs to provide vibration isolation so that the vibration of the exhaust system is not transmitted to the chassis and then to the inside cabin.

### **4.3 Five different Design criterion of Muffler Design**

1. Acoustical criterion
2. Aero dynamical criterion
3. Mechanical criterion
4. Geometrical criterion
5. Economical Criterion

### **4.3.1 Acoustical criterion**

It specifies the minimum noise reduction required from the muffler as a function of frequency.

### **4.3.2 Aero dynamical criterion**

It specifies the maximum acceptable pressure drop through the muffler at given temperature and mass flow.

### **4.3.3 Mechanical criterion**

It specifies the material from which the muffler is fabricated or designed. It is durable and requires less maintained. This is especially important in case of involving high temperature exhaust , corrosive gases ,the gaseous flow is carrying solid particles in suspension that might be deposited on the inner surface of the wall of the muffler and reduce the effectiveness.

### **4.3.4 Geometrical criterion**

It specifies the maximum allowable value and restriction on shape.

### **4.3.5 Economical criterion**

It is vital in the market place. This type of muffler must be inexpensive as possible while designing initial cost as well as operating cost must be considered.

## **4.4 Tailpipe Design**

The tail pipe itself acts as a resonant cavity that couples with the muffler cavity. The effect of exhaust gas flow speed has a detrimental effect on the muffler performance. The length of tailpipe is important parameter in the designing of muffler.

## **4.5 Design of Inlet pipe**

The diameter of inlet pipe is taken same as the diameter of the exhaust port of the engine muffler. The length of the inlet pipe is taken as small as possible so that muffler will occupy less space. There is no specific procedure for designing inlet pipe of the muffler.

## **4.6 Design of Expansion chamber**

This design is most effective at low frequency i.e less the 500 c/s and  $m=10$

$$m = \frac{\text{cross-sectional area of the expansion chamber}}{\text{cross-sectional area of the circular pipe}} \quad (4.1)$$

$$m = \frac{\frac{\pi D^2}{4}}{\frac{\pi d^2}{4}} \quad (4.2)$$

D= Diameter of the expansion chamber.

D= Diameter of the inlet pipe.

$$D^2 = md^2$$

#### 4.6.1 Volume of expansion chamber

$$V_m = \frac{\pi}{4} D^2 \times l \quad (4.4)$$

$V_m$ = volume of expansion chamber.

D = Diameter of expansion chamber.

$l$  = Length of the expansion chamber.

#### 4.6.2 Transmission loss of the muffler

$$TL = 10 \log_{10} \left[ 1 + \frac{1}{4} \left( m - \frac{1}{m} \right)^2 \sin^2 kl \right] \quad (4.5)$$

$$m = \frac{\frac{\pi}{4} D^2}{\frac{\pi}{4} d^2} \quad (4.6)$$

$k$ = sound wave number

$$k = \frac{2\pi fl}{c} \quad (4.7)$$

$f$  = Frequency.

$l$  = Length of muffler proper.

$C$  = speed of sound. [5]

In this study, four different types of muffler are used out of which two are of Reflective type mufflers, one is free flow type and one is hybrid type muffler.

Muffler No. 1(M1) is Original reflective type muffler as shown in figure

### Muffler No.1



Fig.4.1 Original reflective muffler in closed condition



Fig.4.2 Original reflective type muffler in cut section

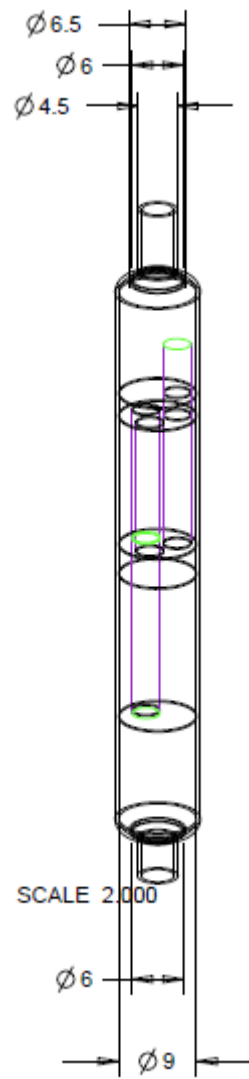


Fig.4.3 Drawing of original reflective M1 muffler

Muffler No. 2(M2) Reflective type muffler as shown in figure

### Muffler No. 2



Fig.4.4 Reflective type muffler in closed condition



Fig.4.5 Reflective type muffler in cut section

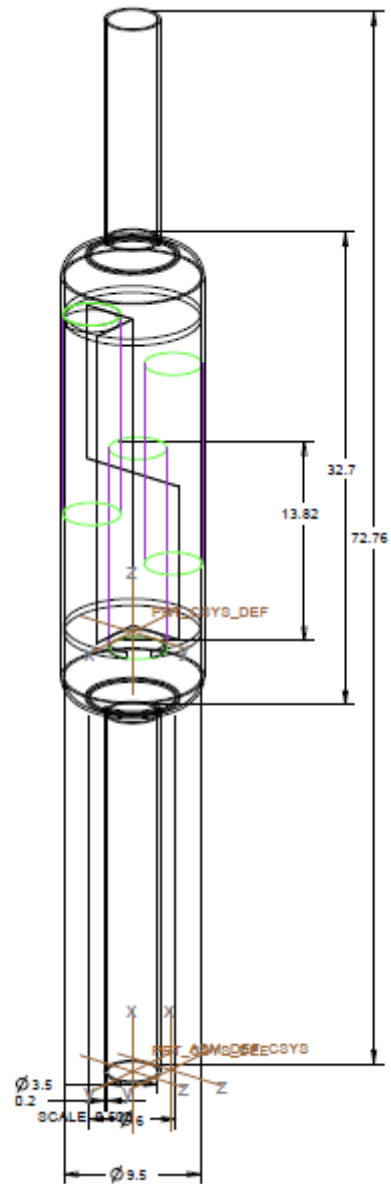


Fig.4.6 Drawing of Reflective muffler M2

Muffler No.3 (M3) Free flow type of muffler is shown in figure

### Muffler No. 3



Fig.4.7 Free flow type muffler in closed section



Fig.4.8 Free flow type in cut section

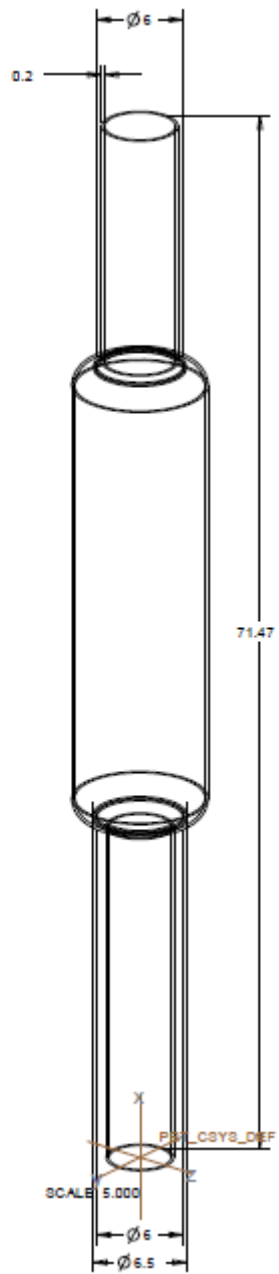


Fig.4.9 Drawing of Free flow type muffler M3

Muffler No.4 (M4) Hybrid type muffler as shown in figure

### Muffler No.4



Fig.4.10 Hybrid type muffler in closed condition



Fig.4.11 Hybrid muffler in open condition



## 4.7 Modification in muffler

In this thesis work, a hybrid muffler (M4) is fabricated by using the techniques of absorptive type and reflective type muffler.

### 4.7.1 Steps for modification in muffler

1. A glass wool is tightly positioned between the two metallic sheets like a sandwich structure.



Fig. 4.13 View of Metallic sheets of M4 muffler

The outer sheet has length 600 mm, width 340 mm and thickness 1.24 mm and the inner round hole perforated sheet has length 600 mm, width 320 mm, thickness 0.85 mm and number of holes 3000(approx.). These round hole perforated sheet is worked as a medium of transferring the air from the exhaust to glass wool, by which glass wool absorb noise and heat from exhaust air.



Fig. 4.14 Metallic sheets with glass-wool

2. These sheets were rolled by roll bending machine and converted it into cylindrical form.



Fig. 4.15 Sheets rolled in bending machine

3. In this step the cylindrical sheet formed in step 2 is welded with TIG welding



Fig. 4.16 welding of cylindrical sheets

4. Some extra glass wool was inserted and pressed into the gap between the sheets.



Fig. 4.17 Inner view of muffler

5. A reflective chamber was positioned as same as earlier in the muffler, so as to reflect the air flow from the exhaust



Fig. 4.18 View of muffler

6. The inlet pipe and outlet pipe are welded by TIG welding.



Fig. 4.19 Ends pipe of muffler

7. New hybrid muffler manufactured



Fig. 4.20 View of muffler M4

# Chapter 5

## Experimental setup and measurements

---

### 5.1 Experimental setup

To study the noise generated by the two-wheeler motorcycle, the parameters like acoustic power/sound pressure level are necessary to be study at different speed of engine.



Fig.5.1 Set-up for Measuring the Acoustic Power

A motorcycle used in this work is “Royal Enfield Bullet motorcycle.” The specification of this motorcycle is as follow

Table 5.1 specifications of motorcycle

Engine	Petrol
Number of cylinder	One
Horse power (B.H.P)	19.8
Weight (in Kg.)	175
Stroke	Four
Displacement	350cc

## 5.2 Measurements

Measurements procedure of different noise parameters involve for calculation of sound power, measurement of sound pressure level at different locations (A, B, C, D and E), and measurement of sound pressure level for frequency spectrum in 1-1 octave band as explained earlier.

### 5.2.1 Measurements of sound power:

Evaluation of sound power is done by two methods

1. Rectangular parallopiped
2. Hemi-sphere parallopiped

In this present work, rectangular parallopiped method is used because maximum dimension of motorcycle is greater than 1m. [1]

In this method, the first step is to make a grid according to the dimensions of the motorcycle. Length, breath and height of motorcycle are 1.9m, 0.5m and 0.95m respectively. The grid is made by placing a motorcycle at centre position and with the help of thread at required positions mark at different points. There are 17 points formed. Sound pressure level is measured for every grid point at different speeds of engine. Different speeds of engine used in this work are 1000, 1500, 2000, 2500, 3000 rpm. Value of sound pressure level is measured in A- weighting. The measurements are taken with M1 and M4 mufflers. The measurement data for sound pressure level from Table 1 and Table 2 in Appendix-A. The method for calculating the  $L_w$  from sound pressure level is given in Appendix-D.

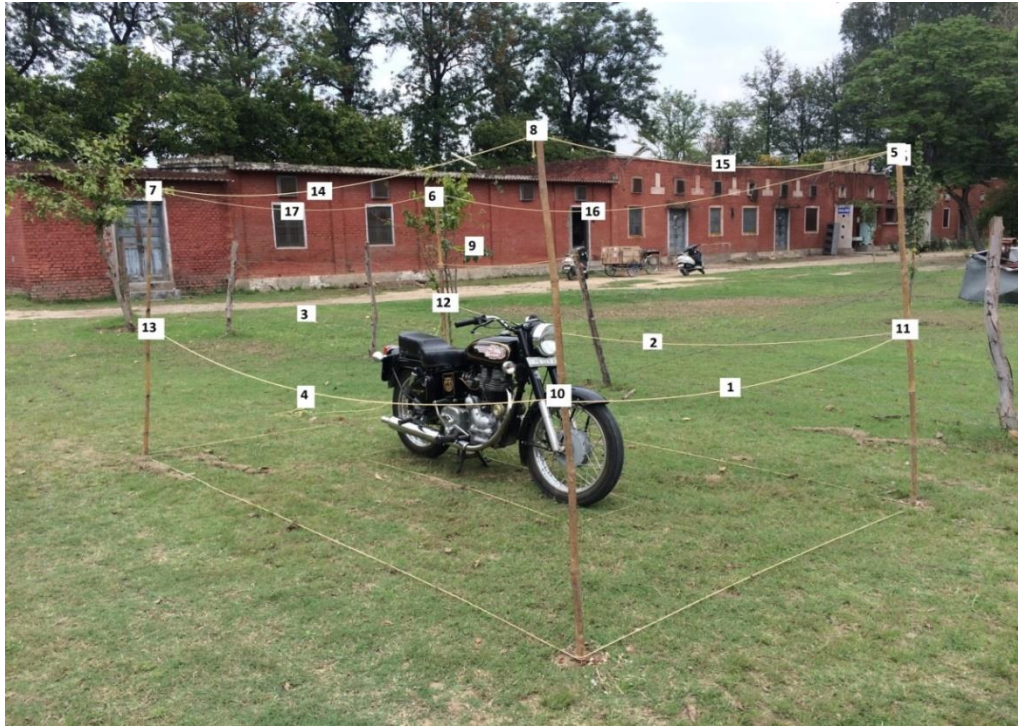


Fig.5.2 showing 17 grid point

### **5.2.2 Measurement of sound pressure level at different points near Engine:**

Sound pressure level is measured at five different locations out of which four location ( A, B, C and D) are at the distance of 1m from the centre of the engine, and the fifth location (E) is at distance of 1m above of the engine of motorcycle at varying engine speed from 1000 to 3000 rpm. The location “A” is front of the motorcycle, location “B” is side of the motorcycle, location “C” is taken at exhaust of the motorcycle, location “D” is other side of the motorcycle and location “E” is above of the engine at the position where the motorcycle driver sit. These measurements will help to find out that location where maximum sound pressure level occurs. The measure data at five locations (A, B, C, D and E) are given from Table -1 to Table-10 in Appendix-B.



Fig.5.3 Location of points A, B, C, D and E

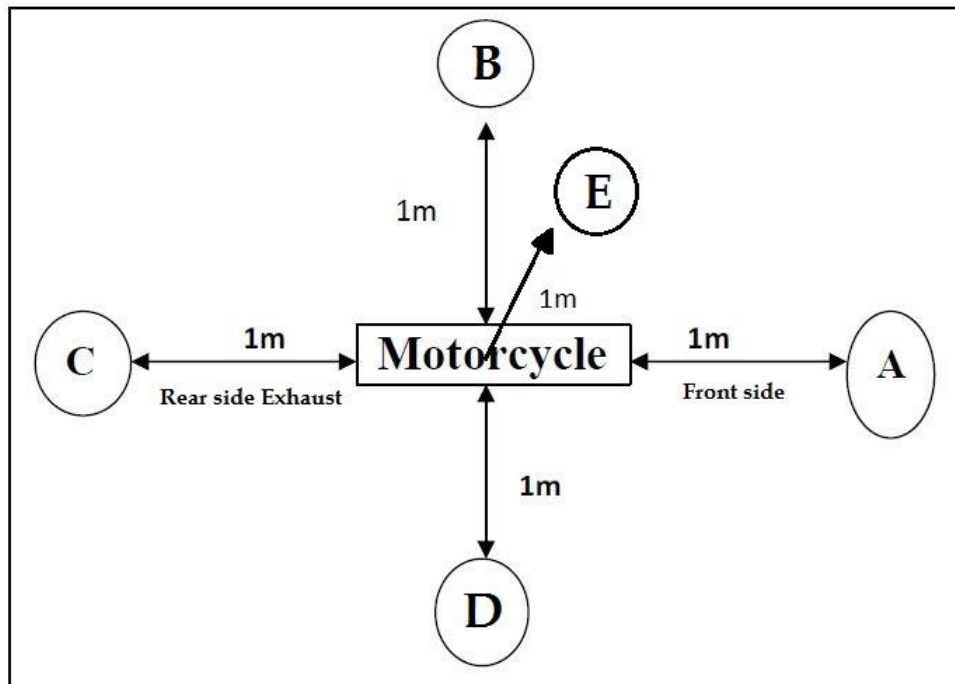


Fig.5.4 Sketch view of Fig.

### 5.2.3 Measurement of sound pressure level for frequency spectrum in 1-1 octave band

The value of sound pressure level at 1-1 octave band gives the high and low value at different frequency level. Measurement is done with and without different types of muffler 1m away from the tail pipe of the muffler at 45° angle.



Fig.5.5 sound level meter [36]

Frequency analyser was carried out at 1m distance from the tailpipe of muffler at 45° degree angle. The data of frequency analyser is measured by “Brüel and kjaer hand held analyser type 2250” and the data was recorded in software of Brüel and kjaer in “BZ 5503 Measurement partner suite.”

# Chapter 6

## Results and Discussion

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After all the measurements, it is required to analyse the noise data by comparing the engine speeds with different types of mufflers. Analysis is done to find out the acoustic power of the motorcycle, sound pressure level, insertion loss, and Frequency spectra.

### 6.1 Determination of Acoustic power

The advantage of measuring acoustic power of source over sound pressure level is that the former does not depend upon distance while the latter depends upon the distance and tells the source power characteristics. Evaluation for acoustic power was carried out on two mufflers i.e original reflective type muffler M1 and new hybrid type muffler M4 at different engine speeds from 1000 to 3000 RPM. Analysis shows the variation between the acoustic power of the motorcycle in dB (A) and engine speed. The method of calculating the  $L_w$  from sound pressure level is given in Appendix- D

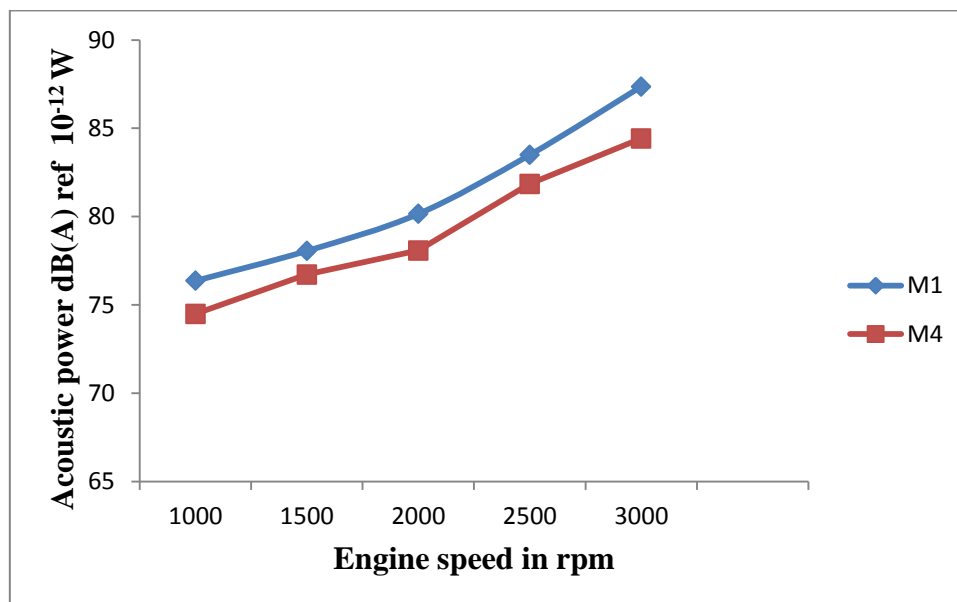


Fig.6.1 Acoustic power of motorcycle in dB (A) Vs. Engine RPM

The figure shows the variation between acoustic power at different engine speeds of motorcycle with M1 and M4 mufflers. Value of acoustic power increases continuously as the speed of engine increases in both M1 and M4 mufflers. The value of acoustic power of motorcycle with M4 muffler is less than the value of acoustic power with M1 muffler. Initial value of acoustic power with M1 muffler at engine speed 1000 rpm is 76.4 dB (A) and with M4 muffler is 74.5 dB (A) and termination value of acoustic power of motorcycle with M1 muffler at engine speed 3000 rpm is 87.4 dB (A) and with M4 muffler is 84.4 dB (A). The difference between acoustic power with M1 and M4 muffler varies between 2-4 dB (A).

## 6.2 Analysis of Sound Pressure level at different points near the Engine

To study the variation of sound pressure level around the vehicle at different speeds, five measurement points were taken namely A, B, C, D and E. which were on the front, left, back, right and above sides of the motorcycle respectively. All these point were located at distance of 1 meter from the motorcycle. Sound pressure level was measured at engine speed from 1000 to 3000 rpm. The comparison was made between M1 and M4 muffler. The variation between sound pressure level and at different engine speed with M1 and M4 muffler at locations A, B, C, D, and E is shown in fig. 6.2 to 6.6. The measurement data of sound pressure level at different location from Table 1 to Table 10 in Appendix-B

### 6.2.1 Sound pressure level at location A:

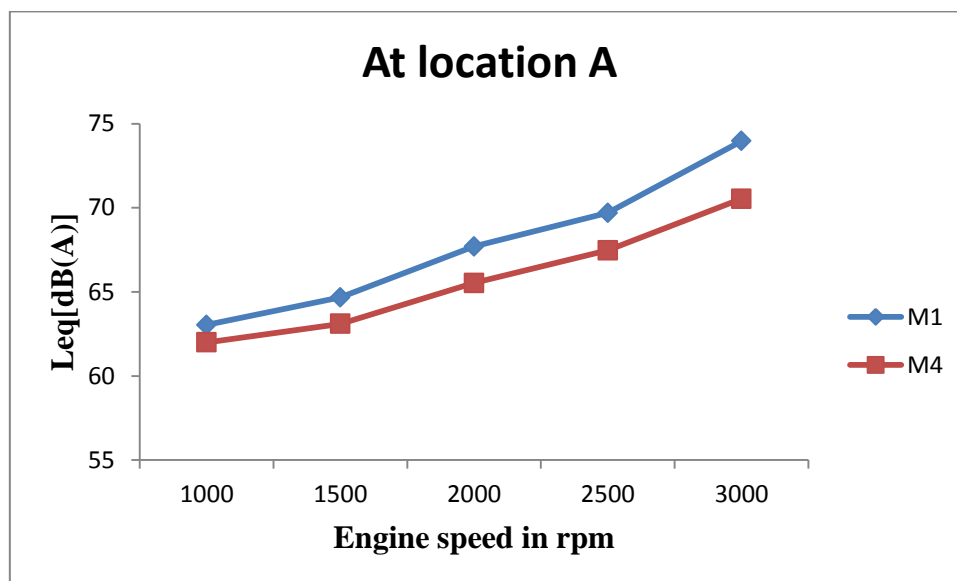


Fig.6.2 Sound pressure level at location A Vs. Engine speed

### 6.2.2 Sound pressure level at location B:

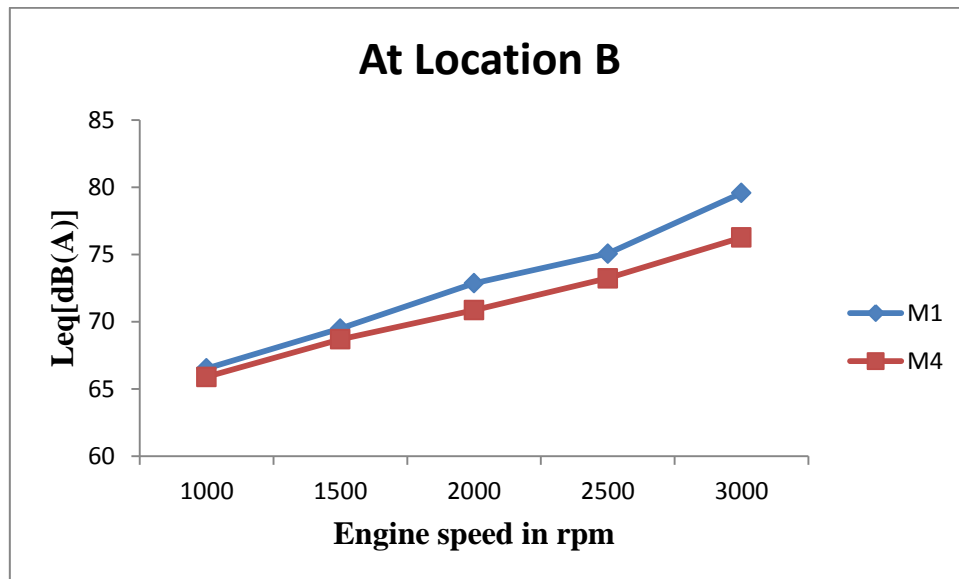


Fig.6.3 Sound pressure level at location B Vs. Engine speed

### 6.2.3 Sound pressure level at location C:

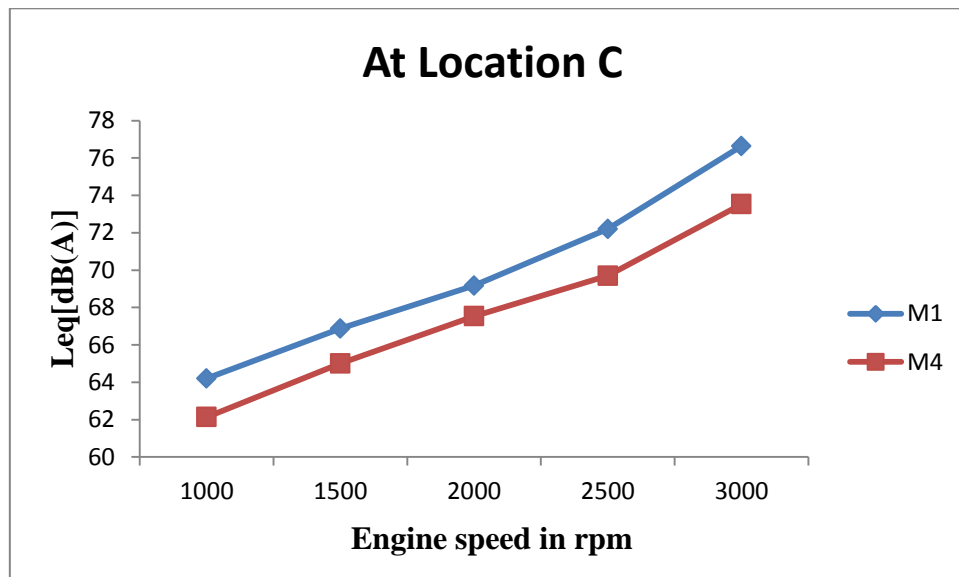


Fig.6.4 Sound pressure level at location C Vs. Engine speed

#### 6.2.4 Sound pressure level at location D:

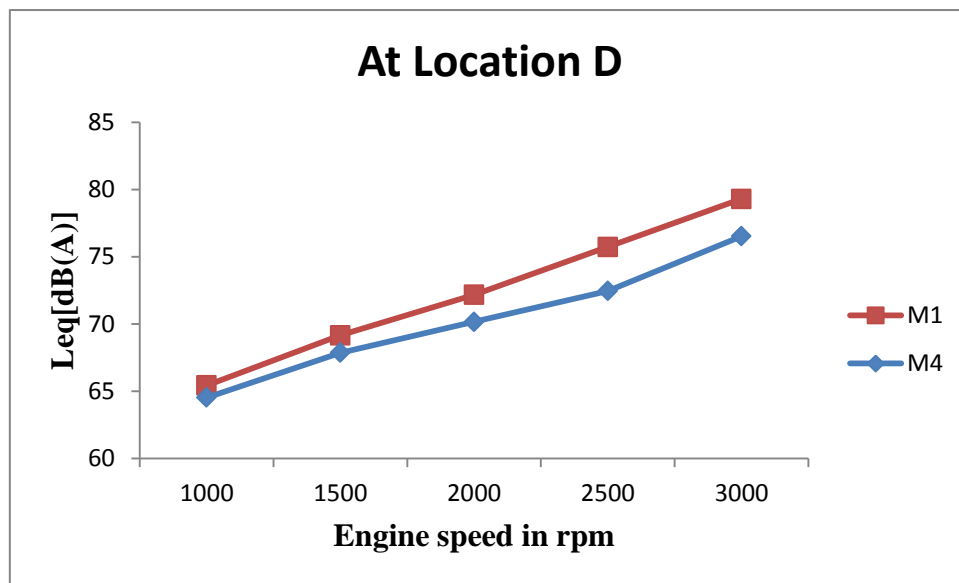


Fig.6.5 Sound pressure level at location D Vs. Engine speed

#### 6.2.5 Sound pressure level at location E:

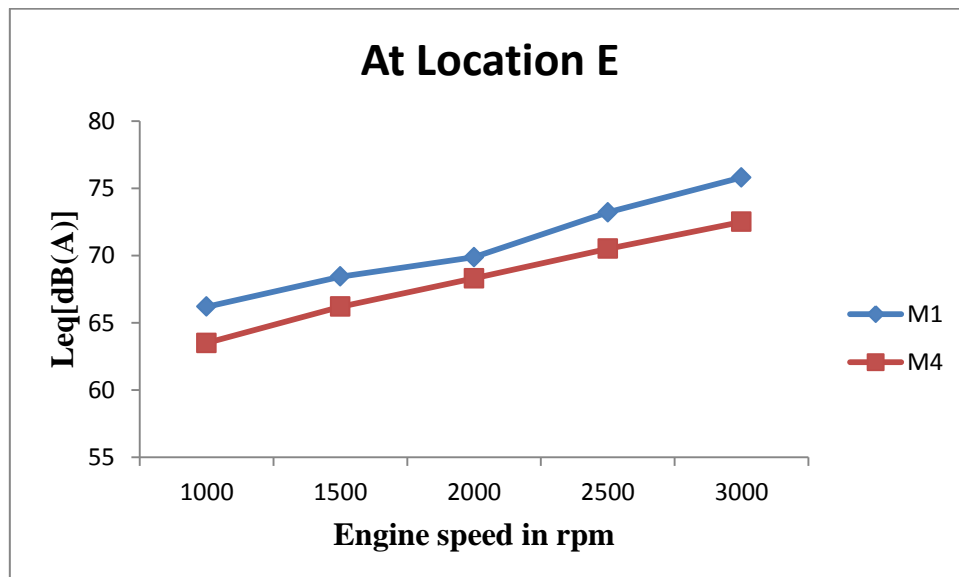


Fig.6.6 Sound pressure level at location E Vs. Engine speed

The figure shows the variation between sound pressure level and engine speed with M1 and M4 muffler. The value of sound pressure level increases continuously as the engine speed increases in each location. It is found that there is 2-3 dB (A) level difference in between M1 and M4 muffler.

At location A fig.6.2 shows that as the engine speed increases sound pressure level increase in both the M1 and M4 mufflers. The difference of sound pressure level between two mufflers varies between 2 to 4 dB (A). Minimum and maximum sound pressure level with M1 and M4 muffler is 63.1 and 62 dB(A) ,79.6 and 76.3 dB(A) respectively.

At location B fig 6.3 shows that as the engine speed increases sound pressure level increase in both the M1 and M4 mufflers. As the engine speed increases, the difference between sound pressure level between M1 and M4 mufflers also increases. Minimum and maximum sound pressure level with M1 and M4 muffler is 66.9 and 66.6 dB (A), 79.6 and 76.3 dB (A) respectively.

At location C fig 6.4 shows that the value of sound pressure level increase gradually as the engine speed increases. The difference between the value of sound pressure level between M1 and M4 muffler is very less. . Minimum and maximum sound pressure level with M1 and M4 muffler is 64.2 and 62.1 dB (A), 76.6 and 73.5 dB (A) respectively.

At location D fig 6.5 shows that the value of sound pressure level increase gradually as the engine speed increases. The difference between the value of sound pressure level between M1 and M4 muffler is less than from location C. Minimum and maximum sound pressure level with M1 and M4 muffler is 65.4 and 66 dB (A), 79.3 and 76.5 dB (A) respectively.

At location E fig 6.6 show that the value of sound pressure level increase as the engine speeds increases. The difference between the sound pressure level between M1 and M4 muffler is more or less constant. Minimum and maximum sound pressure level with M1 and M4 muffler is 66.2 and 63.5 dB (A), 75.8 and 72.5 dB (A) respectively.

It is found that the maximum value of sound pressure level is at position B and D because of location of engine and exhaust and minimum value is at position A because this location lies in front of the motorcycle and there is no any major source of noise.

Table 6.1 percentage increase in sound pressure level as the engine speed increases at different locations

Location	Percentage increase with M1 Muffler (%)	Percentage increase with M4 Muffler (%)
A	26	23
B	18	14
C	19	18
D	21	15
E	14	14

The above table show that the percentage increase in sound pressure level when the engine speed varies 1000 to 3000 rpm at different locations (A, B, C, D and E). It is found that the maximum variation in the percentage is at location D and minimum variation is at point E.

### 6.3 Measurement of sound pressure level

#### 6.3.1 Comparison between mufflers

In this study, the comparison is made between sound pressure level with out and with different mufflers at different engine speeds as shown in fig. 6.7 to 6.11.

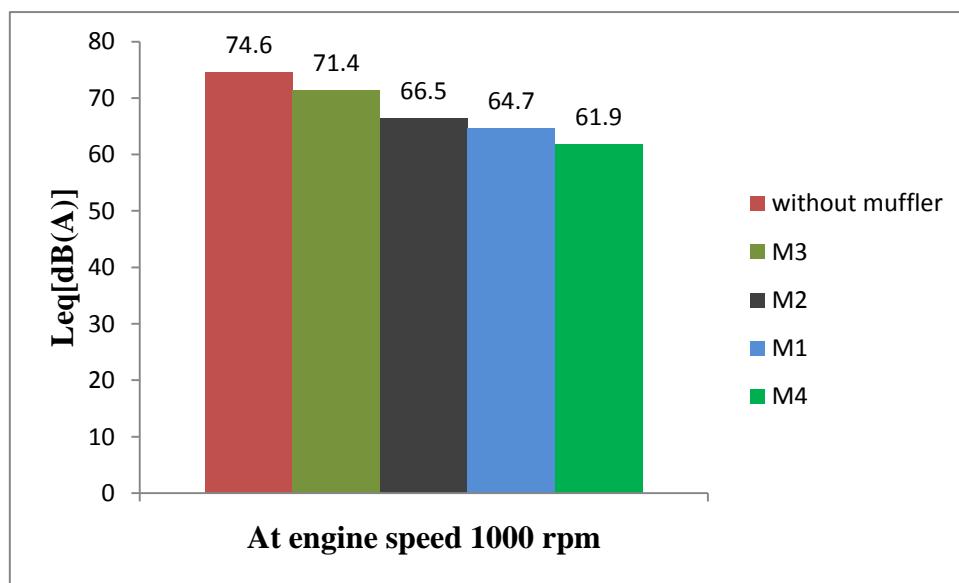


Fig.6.7 Sound pressure level of different mufflers at 1000 engine speed

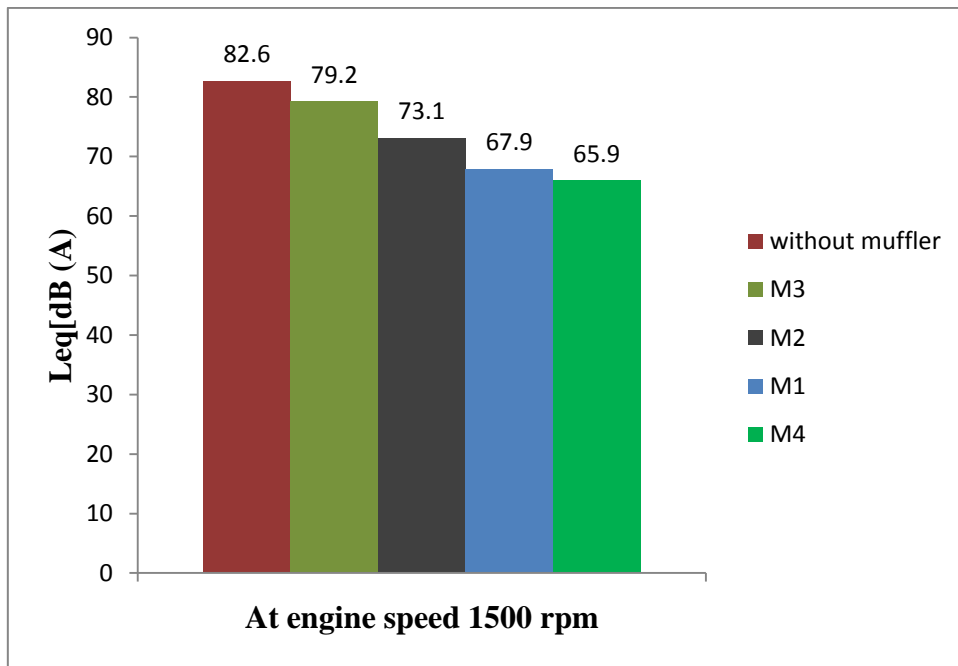


Fig.6.8 Sound pressure level of different mufflers at 1500 engine speed

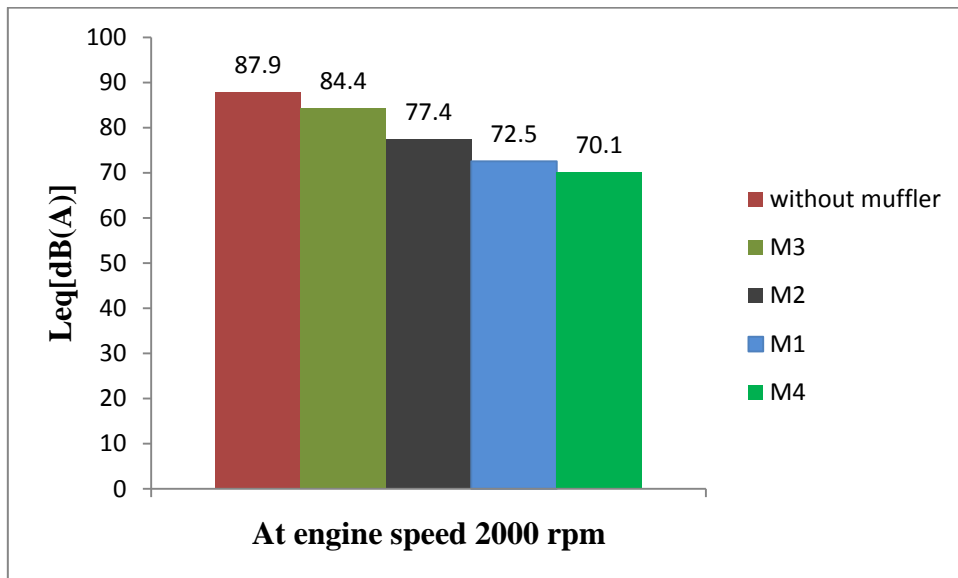


Fig.6.9 Sound pressure level of different mufflers at 2000 engine speed

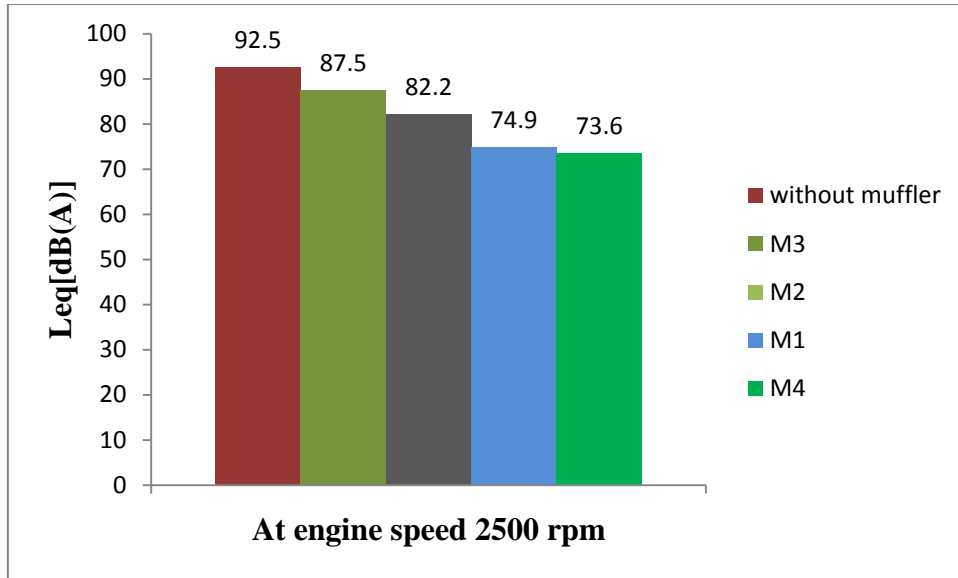


Fig.6.10 Sound pressure level of different mufflers at 2500 engine speed

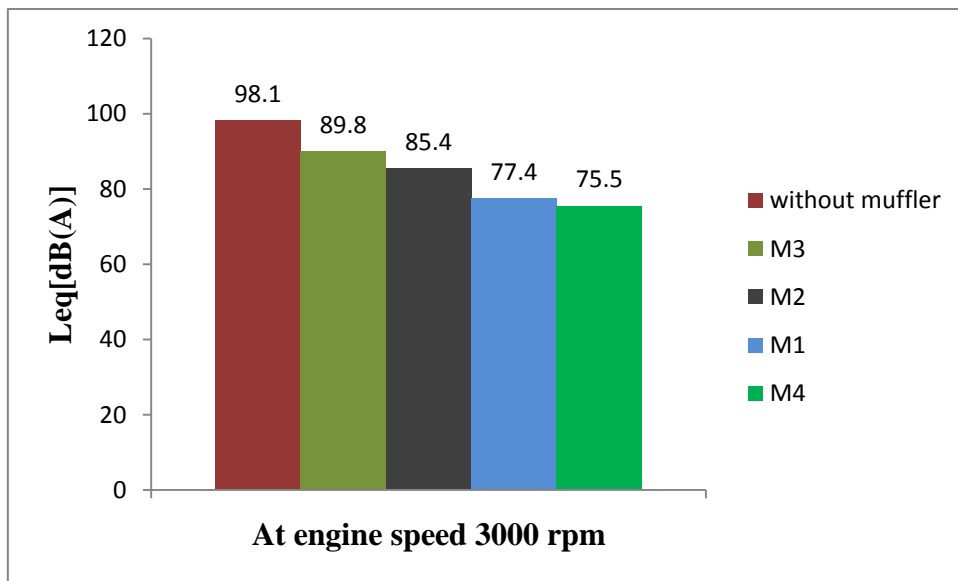


Fig.6.11 Sound pressure level of different mufflers at 3000 engine speed

Above graphs show the effect mufflers at particular engine speed on sound pressure level. At constant engine speed, value of sound pressure level is maximum without muffler and minimum with M4 muffler in all the cases. The decreasing order for each engine speed is without muffler > M3 > M2 > M1 > M4. The difference between sound pressure level of muffler M1 and M4, M2 and M3 are found to be less in each graph respectively. Value of sound pressure level without muffler is very high as compared to other mufflers in each graph. From the above graphs, it's found that vehicle with muffler M4 has minimum noise level.

### 6.3.2 Comparison between different Engine Speeds

In this study, the comparison is made between sound pressure levels with varying engine speed for specific condition as shown in fig. 6.12 to 6.16. Measurements are done 1 m away from the tailpipe of the muffler at  $45^{\circ}$  angle.

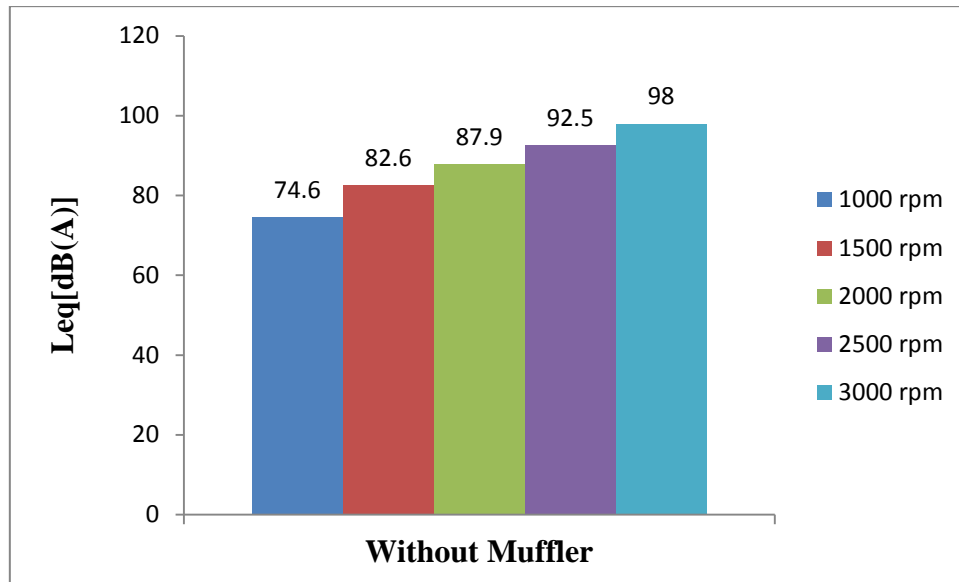


Fig.6.12 Sound pressure level at different engine speeds without muffler

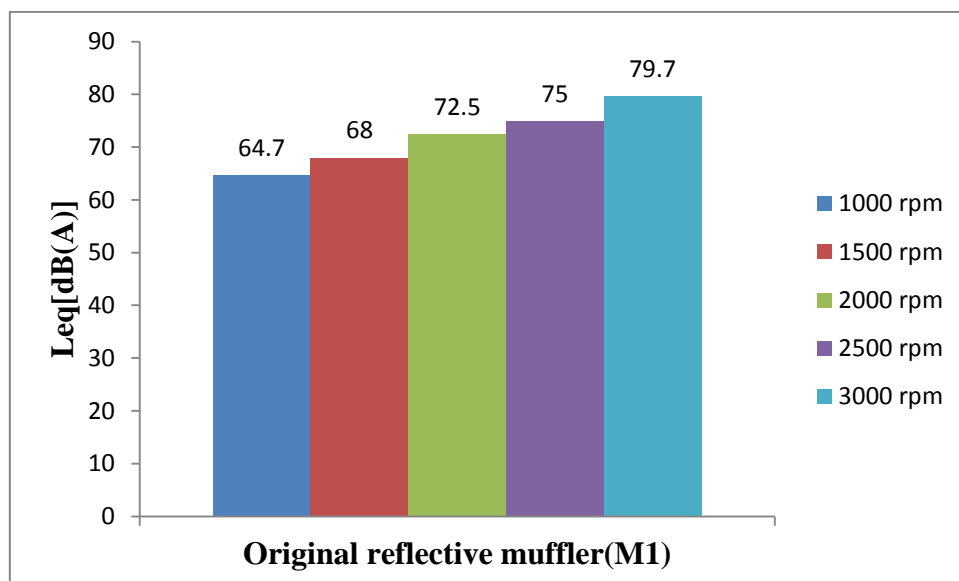


Fig.6.13 Sound pressure level at different engine speeds with M1 muffler

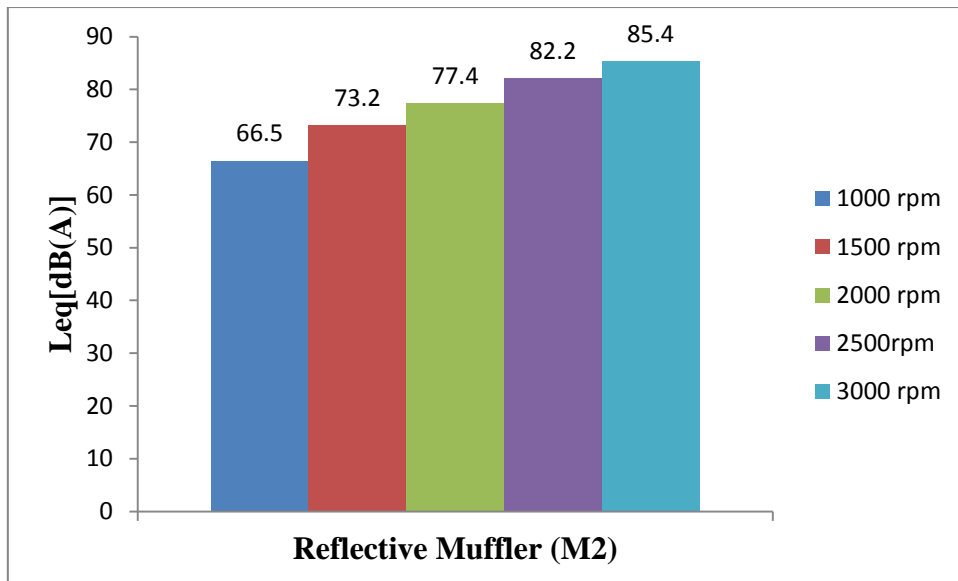


Fig.6.14 Sound pressure level at different engine speed with M2 muffler

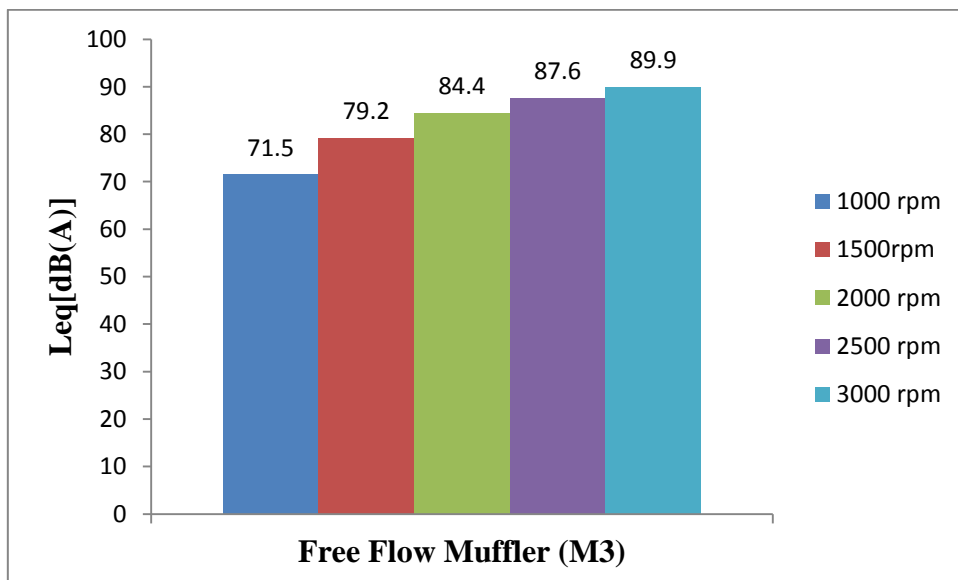


Fig.6.15 Sound pressure level at different engine speeds with M3 muffler

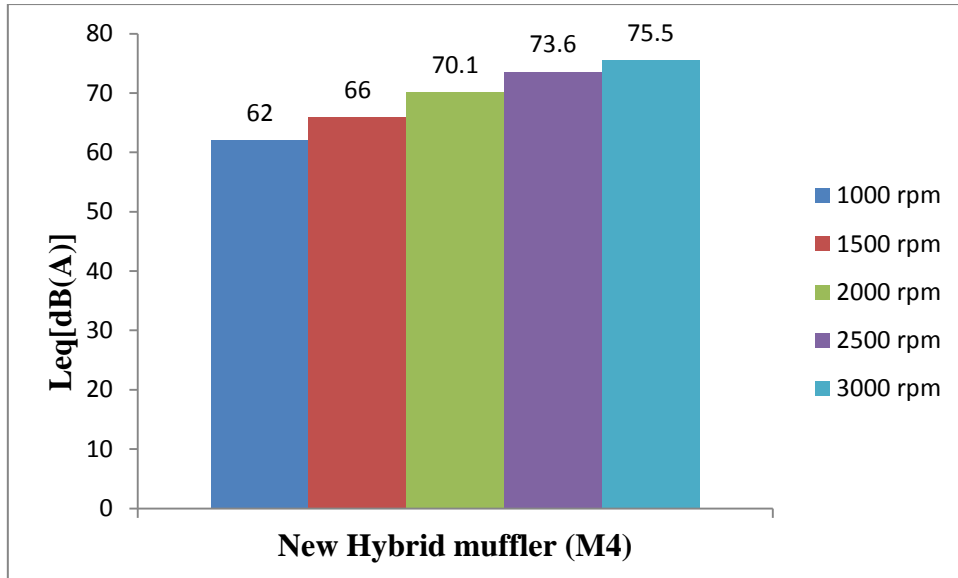


Fig.6.16 Sound pressure level at different engine speeds with M4 muffler

From the above graphs, it's found that as the engine speed increases, sound pressure level also increases. The above graphs show as engine speeds increases, there is increase in sound pressure level, but the differences between the sound pressure level decreases as the engine speed increases. The sound pressure level of M4 muffler is minimum percentage value, so M4 muffler is most effective as compared to other mufflers.

Table 6.2 Percentage increase in sound pressure level at varying Engine speed

Mufflers	Percentage increase in SPL with increase in engine speed 1000 to 3000 rpm
Without muffler	31%
M1	23%
M2	28%
M3	25%
M4	21%

## 6.4 Analysis for frequency spectrum

A frequency spectrum indicates the characteristics of the exhaust noise source. It gives idea of peak frequency which intern would decide the type of control measures. In this analysis, comparison is done between the sound pressure level and frequency for without and with mufflers. The analysis of frequency spectrum is done at 1-1 octave band. This study is shown in fig.6.17 to 6.21

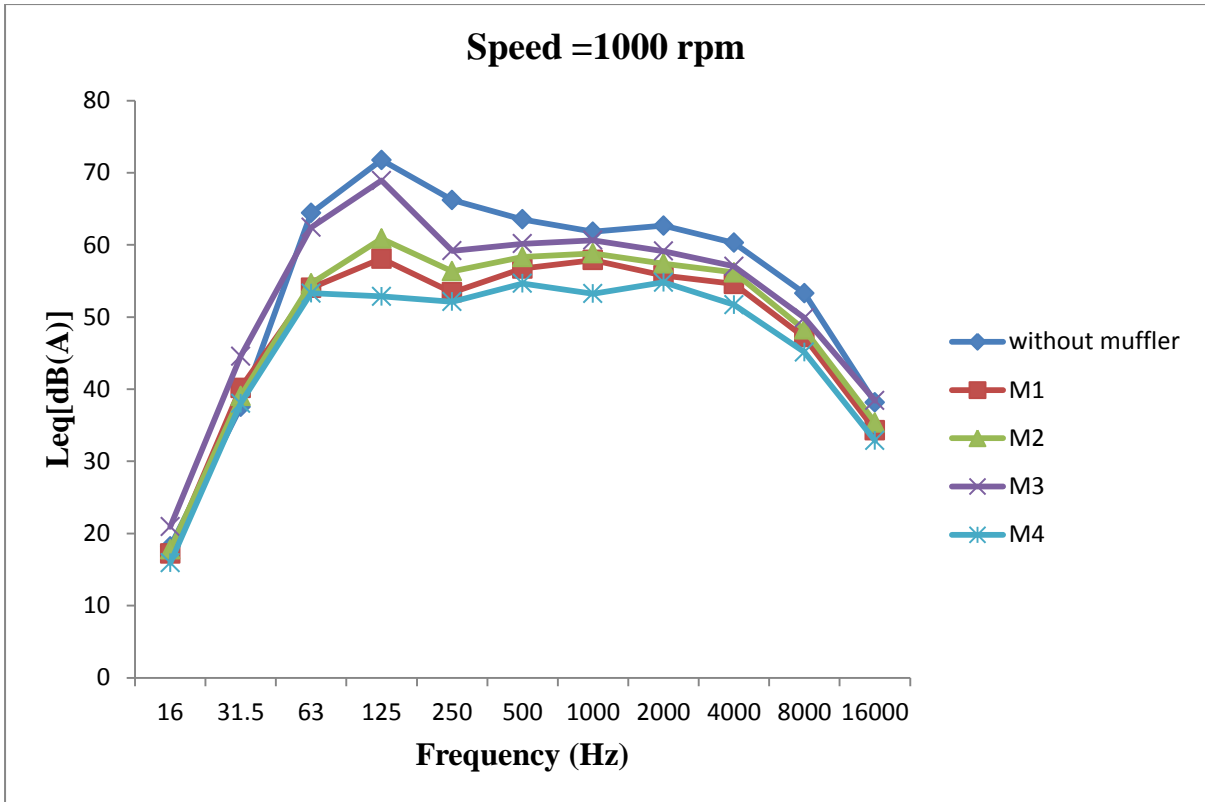


Fig.6.17 Sound pressure level Vs. Frequency

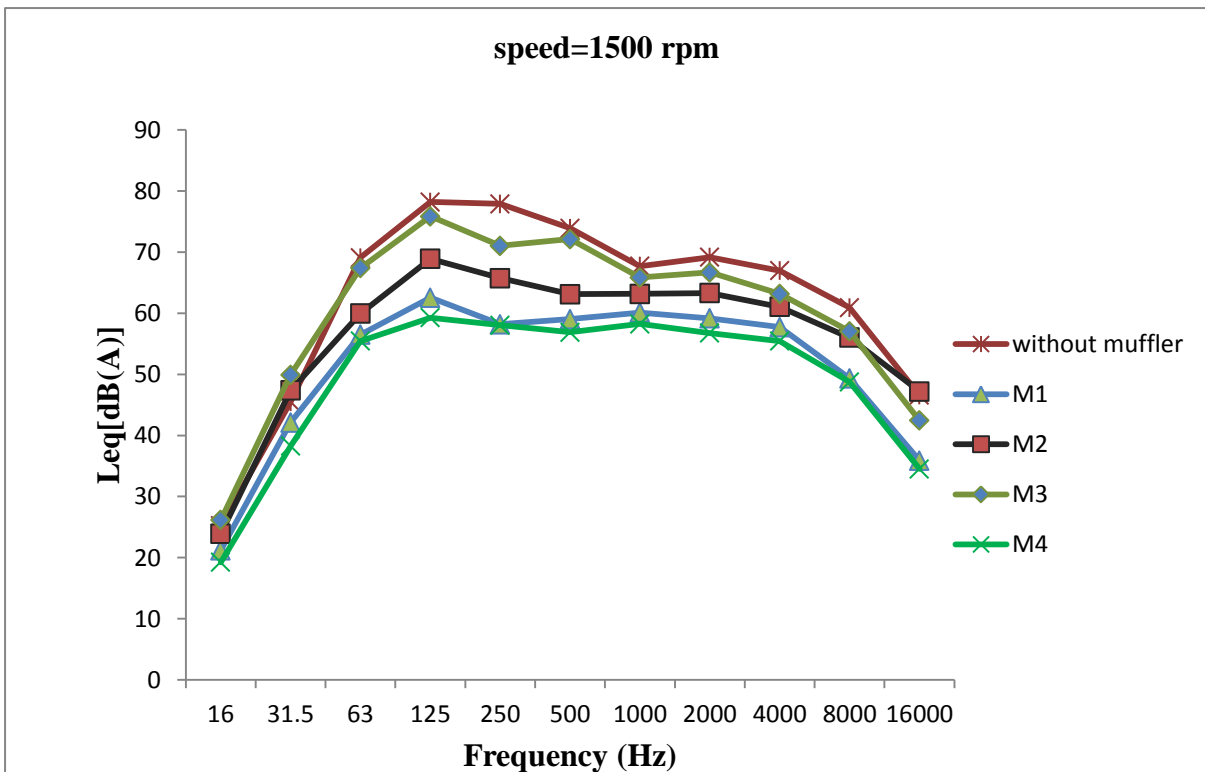


Fig.6.18 Sound pressure level Vs. Frequency

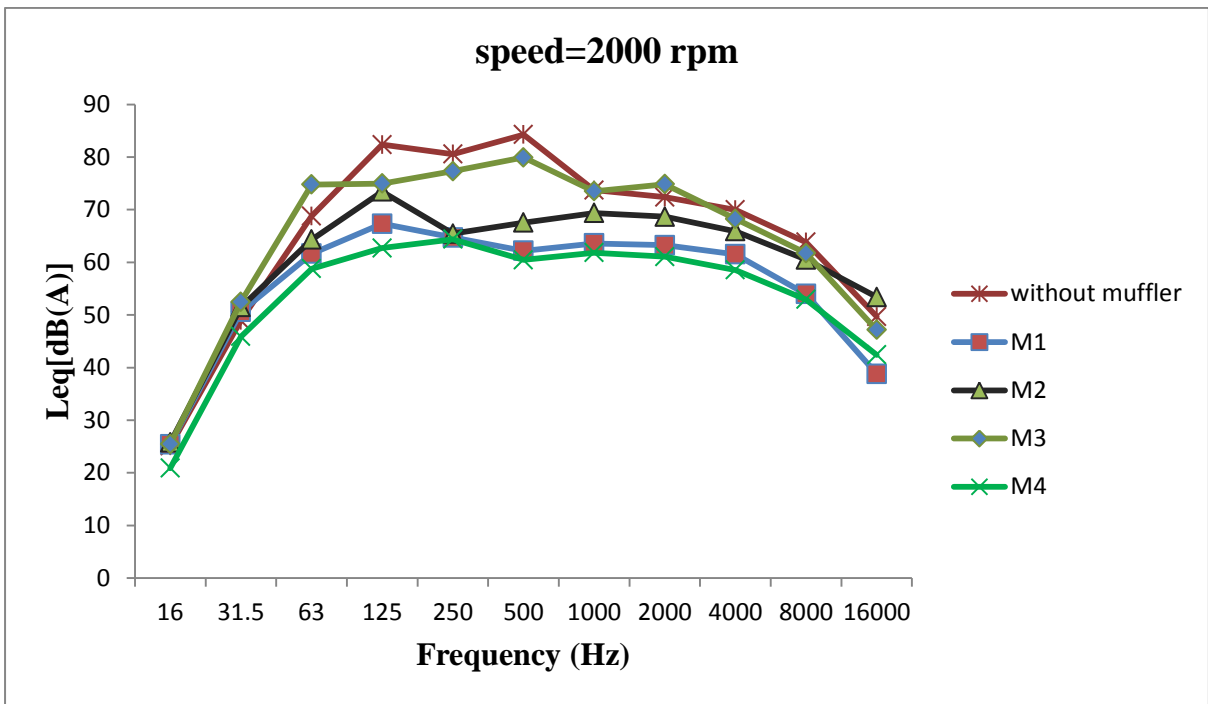


Fig.6.19 Sound pressure level Vs. Frequency

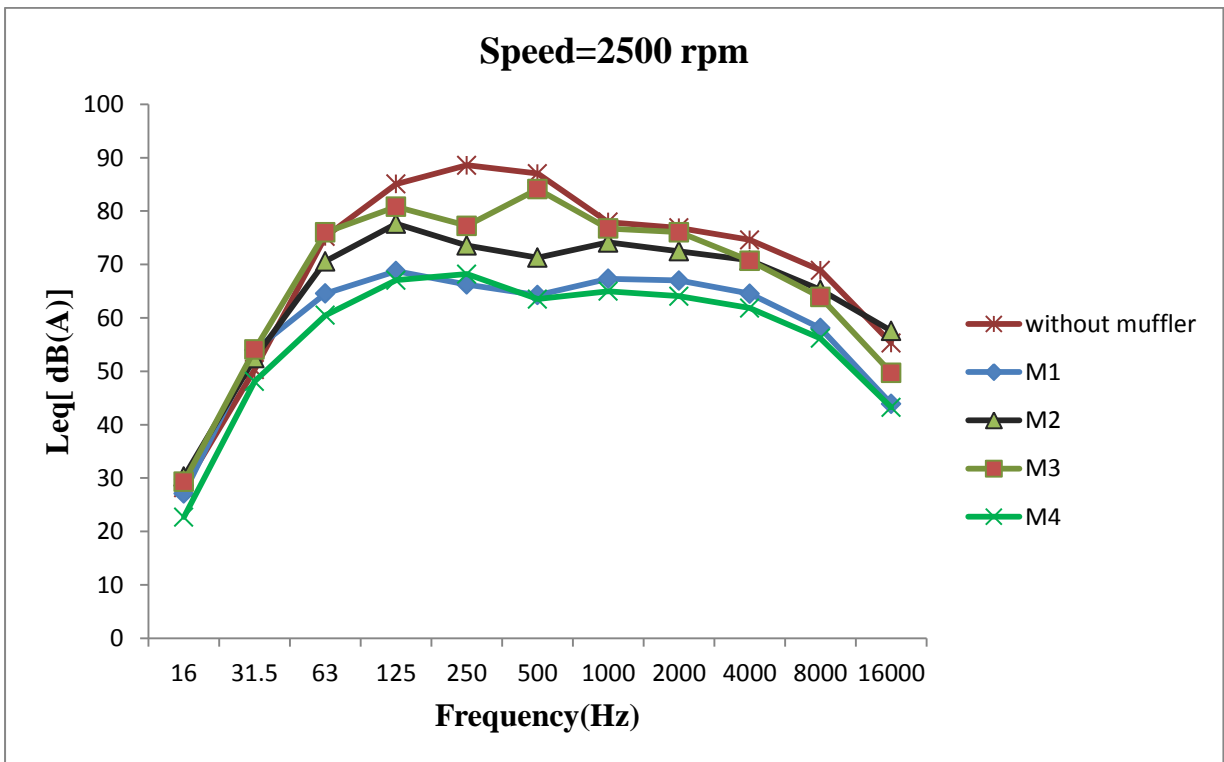


Fig.6.20 Sound pressure level Vs. Frequency

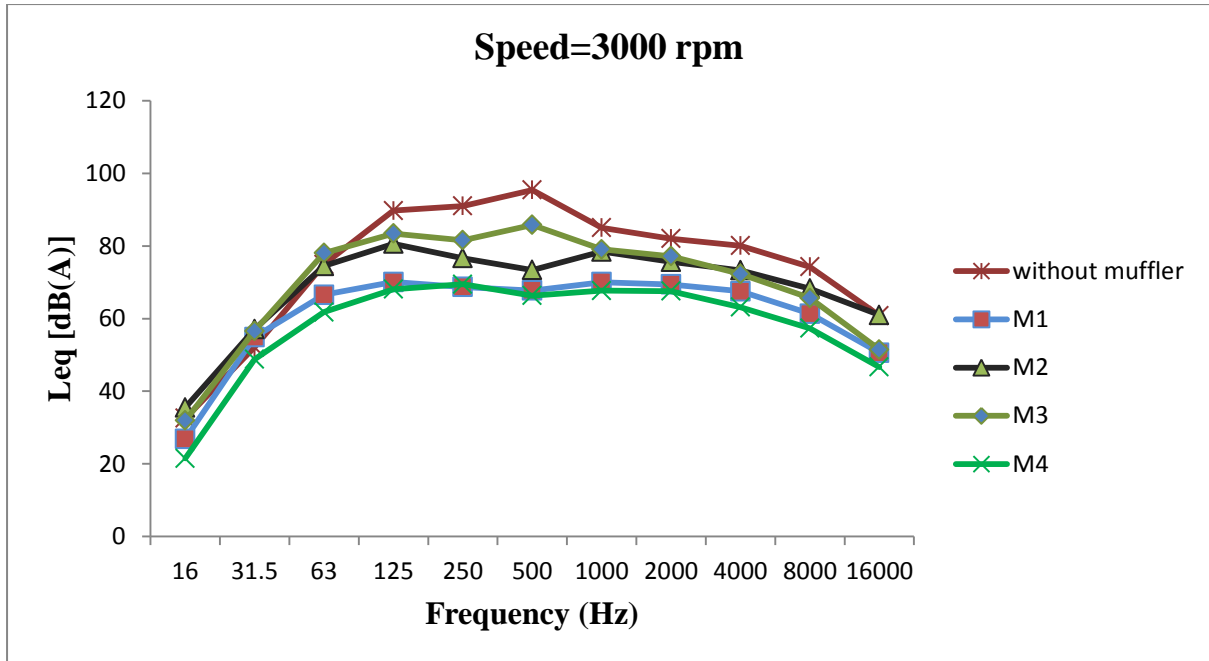


Fig.6.21 Sound pressure level Vs. Frequency

The figures 6.17 to 6.21 show the comparison between sound pressure level and frequency at a particular speed. Table 6.2 show when engine speed increases from 1000 to 3000 rpm, the peak value is shifted towards higher frequency level and it is between the frequency range of 125 to 500 Hz. Sound pressure level also increases with increase in engine speed. For M4 muffler, the sound pressure level remains more or less constant with increase in frequency range 63 to 4000 Hz.

Table 6.3 Relationship between engine speed, peak frequency and sound pressure level.

Engine speed (rpm)	Peak frequency level (Hz)	Sound pressure level dB(A)
1000	63	71.7
1500	125	78.2
2000	125	84.3
2500	250	8.6
3000	500	95.4

## 6.5 Measurement of Insertion loss

Insertion loss is measured to check the effectiveness of muffler at different engine speeds. The insertion loss of different mufflers is calculated by subtracting the sound pressure level without muffler and with using muffler

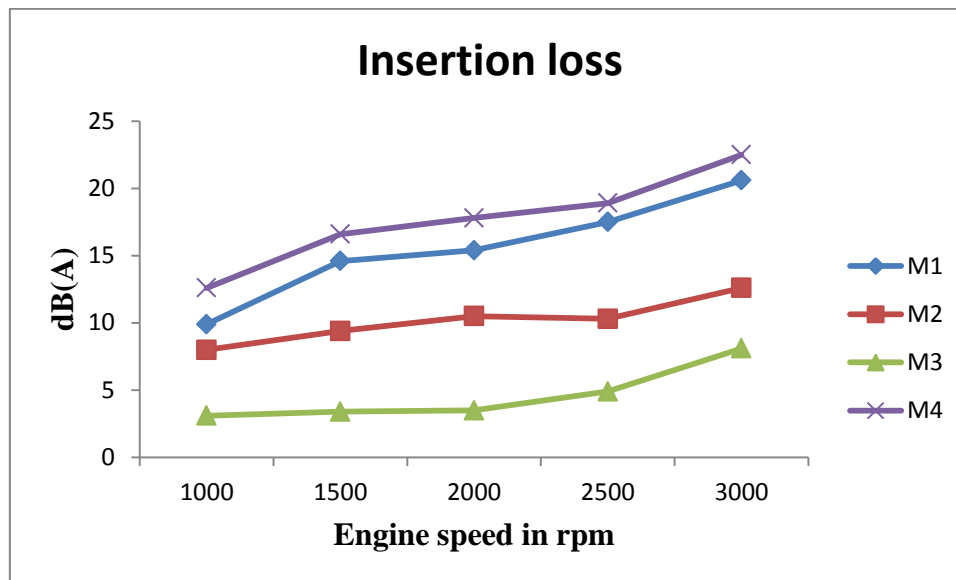


Fig.6.22 Comparison of sound pressure level with different engine speeds

The above graph shows the variation in sound pressure level at different engine speed.

1. For M1 muffler initially at engine speed 1000 rpm, the value of insertion loss is 10 dB (A) and at engine speed 3000 rpm is 20.6 dB (A). The difference between initial and final is 10.6 dB(A)
2. For M2 muffler initially at engine speed 1000 rpm, the value of insertion loss is 8 dB (A) and at engine speed 3000 rpm is 12.6 dB (A). The difference between them is 4.6 dB
3. For M3 muffler initially at engine speed 1000 rpm, the value of insertion loss is 3.1 dB (A) and at engine speed 3000 rpm is 8.1 dB (A). The difference between them is 5 dB
4. For M4 muffler initially at engine speed 1000 rpm, the value of insertion loss is 12.6 dB (A) and at engine speed 3000 rpm is 22.6 dB (A). The difference between them is 10 dB
5. The value of insertion loss increases with increase in engine speed.
6. It is found that maximum value of insertion loss is obtained with M4 muffler so that it is the best muffler with respect to other mufflers.

# Chapter 7

## Conclusion and Scope for Future work

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### 7.1 Conclusions

An analysis of the collected data leads to the following results:-

1. The acoustic power of motorcycle with M4 muffler is found to be less than with M1 muffler at all the engine speeds.
2. The sound pressure level is found to be maximum at location D and minimum at location A for M1 and M4 muffler.
3. Maximum value of sound pressure level at location D is because this location lies in Exhaust noise and gear sides and location A is in front of motorcycle, so there is minimum noise.
4. The decreasing order of sound pressure level at particular speed is found to be without muffler > M3 > M2 > M1 > M4.
5. For a specific muffler the sound pressure level increases with increase in engine speed.
6. The difference between sound pressure level in all types of mufflers decreases with increase in speed engines.
7. As engine speed increases the sound pressure level increases and peak shifts toward higher frequency range.
8. The value of insertion loss increases with the increase in engine speed.
9. Maximum insertion loss is found to be with M4 muffler and minimum for M3 muffler.
10. On the basis of maximum insertion loss, comparison between mufflers, it is found that M4 muffler is the best among all the mufflers.

## **7.2 Scope for Future work**

The presented work can be extended by working upon different points. Some of them are as listed below:

1. A proper muffler can be designed to reduce more noise from an Engine.
2. It is concluded from results that maximum dB is at Frequency range of 63 to 500 Hz. Muffler can be designed to minimize the sound pressure level at these Frequency levels.

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[30 Nov 2014]

# APPENDIX-A

**Table 1**  
**Original reflective type Muffler (M1)**  
 Sound pressure level in dB (A)

Speeds	Grid no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1000 rpm	obs.1	62.8	67.9	64.5	67.2	61.7	61.6	63.1	62.7	68.3	63	63.3	64	64.9	64.3	63.7	64.8	63.4
	obs.2	63.9	68.5	65.3	67.6	62.9	62.1	62.8	63.9	66.7	62.5	62.9	62.9	64.3	64.5	63.6	64.4	63
	obs.3	65.4	67.7	62.8	61.5	63	62.8	66.9	62.7	63.6	63.3	64.6	64.7	63.5	64.5	62.7	63.8	68.4
	Avg.	64.1	68.1	64.2	65.4	62.4	62.2	64.2	63.1	66.2	62.9	63.6	63.9	64.2	64.4	63.3	64.3	64.9
1500 rpm	obs.1	64.6	69.7	66.4	69.4	64.4	63.5	64.5	63.9	68	64.7	65	65.7	66.6	66.2	64.8	66.1	64.6
	obs.2	63	64.4	64.1	68.5	64.3	65.5	65.7	66.4	67.4	65.4	66.6	64.3	64.6	69	67.3	69.3	64.2
	obs.3	64.9	69.6	67.3	69.6	64.7	63.7	64.7	64.1	69.9	64.5	62.8	65	65.8	66.6	67.2	64.9	66.4
	Avg.	64.2	67.9	65.9	69.2	64.5	64.2	65.0	64.8	68.4	64.9	64.8	65.0	65.7	67.3	66.4	66.8	65.1
2000 rpm	obs.1	67.6	72.5	68.6	71.8	65.1	64.7	65.4	65.1	67.8	66.4	66.7	67.1	68.9	68.7	66	69	65.8
	obs.2	67.8	72.2	69.6	72.2	65.3	65.2	65.8	65.8	68.9	66.5	67.4	67.8	69.4	69	66.9	68.8	66.7
	obs.3	67.7	73.2	69.3	72.5	67.1	65.5	66.2	65.8	68.8	66.5	67.2	67.3	68.7	68.7	66	68.9	66.1
	Avg.	67.7	72.6	69.2	72.2	65.8	65.1	65.8	65.6	68.5	66.5	67.1	67.4	69	68.8	66.3	68.9	66.2
2500 rpm	obs.1	69.2	73.7	71.5	73.6	68.6	68.1	69.2	68.7	72.2	69.8	69.5	70.4	71.4	70.8	69.3	71.3	69
	obs.2	69.3	74.2	72.7	77.9	71.5	70.1	71.3	71.3	75.1	72.6	72.4	72.2	73.6	74.3	72.1	73.7	70.8
	obs.3	70.6	75.4	72.4	75.7	68.9	68.4	69.4	69.1	72.3	69.3	70.1	70.4	71.5	71.5	69.2	71.4	69.3
	Avg.	69.7	74.3	72.2	75.7	69.6	68.8	69.9	69.7	73.2	70.6	70.7	71	72.2	72.2	70.2	72.1	69.7
3000 rpm	obs.1	73.3	78.2	75.1	78.5	71	71.5	72.7	71.9	73.9	74	73.5	74.9	75.9	76.1	71.9	75.6	73.2
	obs.2	74.4	80.9	76.8	79.8	73.3	73.2	73.7	73.1	76.5	74.2	74.9	74.9	76.4	77.1	74.1	76.9	74.5
	obs.3	74.2	79.6	76.6	79.6	73.6	73.3	74.8	74.1	77	73.9	74.6	75.1	76.2	76.2	73.7	76.9	74.3
	Avg.	73.9	79.6	76.2	79.3	72.6	72.7	73.7	73.1	75.8	74	74.1	74.9	76.2	76.5	73.2	76.5	74

**Table 2****Hybrid type Muffler (M4)**

Sound pressure level in dB(A)

Speed	Grid no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1000 rpm	obs.1	62	66.7	62.1	66	61.6	60.9	61.6	61.6	63.8	62.6	60.8	60.8	61.1	62.9	61.6	63.5	60.3
	obs.2	62.2	66.9	62.5	66.2	61.2	60.5	61.2	61.8	63.2	62.2	60.5	61.3	61.5	62.5	61.9	63.8	60.5
	obs.3	61.8	66.2	61.8	65.8	61.8	60.2	61.9	61.4	63.5	62.9	60.9	60.2	60.9	63.5	62.2	63.2	60.8
	avg.	62.0	66.6	62.1	66.0	61.5	60.5	61.6	61.6	63.5	62.6	60.7	60.8	61.2	63.0	61.9	63.5	60.5
1500 rpm	obs.1	63.1	68.7	65	68.5	62.2	61.8	62.8	62.6	66.1	63.5	64	64.5	65.8	65.8	62.7	66	62.9
	obs.2	63.4	68.5	64.7	68.2	62.5	61.5	62.7	62.9	66.5	63	64.5	64.9	65	65.4	62.5	66.2	62.2
	obs.3	62.8	68.9	65.3	69	62	62.2	63.1	62.2	66	63.9	63.9	64.2	66.2	65.2	62.9	65.8	62.5
	avg.	63.1	68.7	65.0	68.6	62.2	61.8	62.9	62.6	66.2	63.5	64.1	64.5	65.7	65.5	62.7	66.0	62.5
2000 rpm	obs.1	65.2	71.1	67.5	70.2	65.9	63.2	63.9	63.5	66.5	64.2	65.9	60.2	66.2	66.5	64	66.5	64.3
	obs.2	65.9	71	67.2	69.8	65.5	63.5	63.2	63.9	66.3	64.9	66.2	60.6	65.8	66.9	64.5	66.8	64.6
	obs.3	65.5	70.5	67.9	70.5	65.2	63.9	63.5	63.2	66.9	64.5	66	60.5	66.5	66.2	64.1	65.9	64.9
	avg.	65.5	70.9	67.5	70.2	65.5	63.5	63.5	63.5	66.6	64.5	66.0	60.4	66.2	66.5	64.2	66.4	64.6
2500 rpm	obs.1	69.7	72.4	69.4	72.7	67.2	67.5	67.6	67.7	70.7	68	68.7	68.4	70.2	70.6	69.1	73.6	70.1
	obs.2	69.2	72.5	69.5	72.5	67.8	67.9	67.2	67.5	70.2	68.5	68.2	68.9	70.5	70.2	70.3	73.9	70.6
	obs.3	70.2	71.8	70.2	72.2	67.3	67.2	67.3	67.9	70.6	68.2	68.2	68.6	70.9	70.2	70.6	73.2	69.5
	avg	69.7	72.2	69.7	72.5	67.4	67.5	67.4	67.7	70.5	68.2	68.4	68.6	70.5	70.3	70.0	73.6	70.1
3000 rpm	obs.1	70.5	76.5	73.2	76.2	69	69.2	70.5	69.2	70.5	72	71.5	72.8	73.8	74.5	69.5	73.4	70.9
	obs.2	70.9	76.2	73.5	76.5	70.2	70.3	70.1	70.4	71.1	72.5	71.2	71	73.2	74.9	70.3	73.9	71.2
	obs.3	70.2	76.1	73.9	76.9	69.5	69.4	69.8	69.9	70.6	71.8	71.9	72.5	74	74.1	69.2	73.9	70.6
	avg.	70.5	76.3	73.5	76.5	69.6	69.6	70.1	69.8	70.7	72.1	71.5	72.1	73.7	74.5	69.7	74.2	70.9

## APPENDIX-B

**Table 1**

**With Muffler M1 at Engine speed 1000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	62.8	63.9	65.4	64.1
B	67.9	68.5	67.7	68.1
C	64.5	65.3	62.8	64.2
D	67.2	67.6	61.5	65.4
E	68.3	66.7	63.6	66.2

**Table 2**

**With Muffler M1 at Engine speed 1500 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	64.6	63	64.9	64.2
B	69.7	64.4	69.6	67.9
C	66.4	64.1	67.3	65.9
D	69.4	68.5	69.6	69.2
E	68	67.4	69.9	68.4

**Table 3**

**With Muffler M1 at Engine speed 2000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	67.6	67.8	67.7	67.7
B	72.5	72.2	73.2	72.6
C	68.6	69.6	69.3	69.2
D	71.8	72.2	72.5	72.2
E	67.8	68.9	68.8	68.5

**Table 4**

**With Muffler M1 at Engine speed 2500 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	69.2	69.3	70.6	69.7
B	73.7	74.2	75.4	74.4
C	71.5	72.7	72.4	72.2
D	73.6	77.9	75.7	75.7
E	72.2	75.1	72.3	73.2

**Table 5**

**With Muffler M1 at Engine speed 3000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	73.3	74.4	74.2	73.9
B	78.2	80.9	79.6	79.5
C	75.1	76.8	76.6	76.2
D	78.5	79.8	79.6	79.3
E	73.9	76.5	77	75.8

**Table 6**

**With Muffler M4 at Engine speed 1000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	62	62.2	61.8	62
B	66.7	66.9	66.2	66.6
C	62.1	62.5	61.8	62.1
D	66	66.2	65.8	66
E	63.8	63.2	63.5	63.5

**Table 7**

**With Muffler M4 at Engine speed 1500 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	63.1	63.4	62.8	63.1
B	68.7	68.5	68.9	68.7
C	65	64.7	65.3	65
D	68.5	68.2	69	68.5
E	66.1	66.5	66	66.2

**Table 8**

**With Muffler M4 at Engine speed 2000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	65.2	65.9	65.5	65.5
B	71.1	71	70.5	70.8
C	67.5	67.2	67.9	67.5
D	70.2	69.8	70.5	70.2
E	66.5	66.3	66.9	66.5

**Table 9**

**With Muffler M4 at Engine speed 2500 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	69.7	69.2	70.2	69.7
B	72.4	72.5	71.8	72.2
C	69.4	69.5	70.2	69.7
D	72.7	72.5	72.2	72.4
E	70.7	70.2	70.6	70.5

**Table 10**

**With Muffler M4 at Engine speed 3000 rpm**

Sound pressure level in dB (A)

Locations	Obs.1	Obs.2	Obs.3	Avg.
A	70.5	70.9	70.2	70.5
B	76.5	76.2	76.1	76.2
C	73.2	73.5	73.9	73.5
D	76.2	76.5	76.9	76.5
E	70.5	71.1	70.6	70.7

## APPENDIX- C

**Table 1**

**Insertion Loss by M1 and M2 Mufflers**

Sound pressure level in dB (A)

RPM	Without muffler dB(A)	M1 dB(A)	insertion loss by M1	M2 dB(A)	insertion loss by M2
1000	74.6	64.7	9.9	66.5	8
1500	82.6	68	14.6	73.2	9.4
2000	87.9	72.5	15.4	77.4	10.5
2500	92.5	75	17.5	82.2	10.3
3000	98	77.4	20.6	85.4	12.6

**Table 2**

**Insertion loss by M3 and M4 Muffler**

Sound pressure level in dB (A)

RPM	without muffler dB(A)	M3 dB(A)	insertion loss by M3	M4 dB(A)	insertion loss by M4
1000	74.6	71.5	3.1	62	12.6
1500	82.6	79.2	3.4	66	16.6
2000	87.9	84.4	3.5	70.1	17.8
2500	92.5	87.6	4.9	73.6	18.9
3000	98	89.9	8.1	75.5	22.5

## APPENDIX-D

Acoustic power is calculated with the help of sound pressure level. Sound power is calculated from the formula:

$$L_w = L_p + 10 \log_{10} \left( \frac{S}{S_0} \right) \text{ dB}$$

$$\text{Where } L_p = 10 \log_{10} \left[ \frac{1}{N} \sum_{i=1}^N 10^{0.1 p_i} \right]$$

$L_p$  = sound pressure level averaged over the measurement surface dB,  
reference sound pressure is 20 micropascals.

$L_{pi}$  = A-weighted sound pressure level resulting from  $i^{\text{th}}$  measurement at the designated points, dB

$N$  = total number of measurements.

$L_w$  = Sound power in dB (A) (ref.  $10^{-12}$ W)

$S_0$  = Reference area (taken as  $\text{m}^2$ )

$S$  = Hypothetical surface area

Length,  $a = 1.95$  m

Breath,  $b = 1.25$  m

Height,  $c = 1.95$  m

Area,  $S = ab + 2(ac + bc)$

$S = 15.11 \text{ m}^2$

$$L_w = L_p + 10 \log_{10} \left( \frac{S}{S_0} \right) \text{ dB}$$

The Equation is reduced to:

$$L_w = L_p + 10 \log_{10}(15.11/1)$$

$$L_w = L_p + 11.79$$