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(THERMAL ENGINEERING STREAM)

MODEL ING AND PERFORMANCE EVALUATION OF A SIMPLE REACTIVE MUFFLER OF VEHICLES USING CFD.

BY

DESSALEGN ABERA WAKTOLE

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Faculty of Technology

Mechanical Engineering Department

(Thermal Engineering Stream)

Modeling and Performance Evaluation of a Simple Reactive Muffler of Vehicles Using CFD.

A thesis submitted to school of graduate studies in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering in the Addis Ababa Institute of Technology.

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Candidate's Declaration

I hereby declare that the work which is being presented in this thesis entitled "Modeling and Performance Evaluation of a Simple Reactive Muffler of Vehicles Using CFD" is original work of my own, hasn't been presented for a degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

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With Regards,

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NOMENCLATURE

SYMBOLS	DESCRIPTION
A	Cross sectional area of circular pipe.
c	Speed of sound. (M/s).
C	Compression of wave
D	Diameter of the expansion chamber.
d	Diameter of the circular pipe.
f	Frequency.
K	Wave number.
M	Area ratio
P	Pressure.
R	Rarefaction of wave.
	: D Y H O H Q J W
!	Density of gas
Hz	Hertz
D_b	Decibel.
P_{inc}	Incident power.
p_o	Reference Pressure.
P_{tra}	Transmitted pressure.
TL	Transmission Loss.
W/m^2	Watt per meter square.
W_{inc}	Incident wave.
W_{tra}	Transmitted Wave.
— S D	Micro Pascal.

ABBREVATIONS

BEM	Boundary Element Method.
CFD	Computational Fluid Dynamics.
MPP	Micro Perforated Panels.
PTS	Permanent threshold shift.
S.I	Spark ignition.
SPL/L_P	Sound Pressure Level.
T.D.C	Top dead center
TTS	Temporary threshold shift.

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ABSTRACT

One of the components in the exhaust system of vehicle is muffler. The purpose of the muffler is to reduce the exhaust noise produced by the engine. The main objective of this study is modeling performance evaluation of a simple reactive muffler of vehicles using CFD. Simple expansion chamber muffler has been modeled numerically using Computational Fluid Dynamics (CFD) in order to determine its acoustic response. The CFD model consists of an axisymmetric grid with a single period sinusoid of suitable amplitude and duration imposed at the inlet boundary.

The time history of the acoustic pressure and the velocity is recorded at two points, one point in the inlet pipe and the other point in the outlet pipe. These time histories are Fourier transformed and the Transmission Loss (TL) of the muffler is calculated. The mean flow has also been considered. The mean flow model of the muffler is done using finer mesh and with a suitable inlet velocity applied at the inlet boundary and the pressure drop across the muffler is found. The performance of the muffler is evaluated based on Transmission Loss, Insertion Loss and Backpressure.

The simulation of the muffler was carried out using FLUENT software package. GAMBIT was used to create a mesh and to define the boundary conditions of the required object, which is ready and analyzed by FLUENT. The version used is FLUENT 6.3.26. The solver implemented was an axisymmetric, segregated implicit solver with second order implicit time stepping. Second order upwind discretization was used for the density, momentum, energy, turbulent kinetic energy and turbulent dissipation rate equations. PISO pressure velocity coupling is used. The Wilcox k-ω model for closure. The working fluid was air with the density modeled assuming an ideal gas. The boundary conditions consist of a velocity inlet, a pressure outlet and series of walls. The CFD results are compared with numerical results. Transmission loss vs. frequency curves are analyzed.

Expansion chamber mufflers have been widely studied and results show that the larger the expansion ratio the greater the Transmission Loss. It is a good practice to design a muffler to work best in the frequency range where the engine has the highest sound energy.

Keywords: - Transmission Loss (TL), Back pressure (BP); Insertion Loss (IL)

CHAPTER 1- INTRODUCTION

1.1. Background [1].

Vehicle engines generate noise because of the pressure wave created during the (sudden) opening of the exhaust valves of the engine. The noise is unwanted. Because exhaust noise must meet legislative targets, customer expectations and cost reduction which call for design optimization of the exhaust systems in the design phase. One of the components in the exhaust system of a vehicle is the muffler. The purpose of the muffler is to reduce the exhaust noise produced by the engine. Mufflers usually consist of:

- The tubular metal jacket
- Perforated tubes
- The expansion chamber.

The arrangement of these components will guide the exhaust gas to flow from the inlet pipe of muffler to the outlet (tail pipe) inside the muffler, the sound/noise energy is absorbed by muffler linig, or reflected back to the engine before the gas flows out to the atmosphere. The noise cancellation will reduce the noise that radiated by the vehicle to the surrounding.

Today's vehicles are equipped with two types of muffler, either:

- The reflective muffler, which consists of a number of tubular elements of different transverse dimensions, joined together so as to cause, at every junction, impedance mismatch and hence reflection of substantial part of the incident acoustic energy back to the source.
- The dissipative muffler, which consists of ducts lined on the inside with acoustically absorptive materials. It operates by the dissipation of acoustic energy usually within porous fibrous materials (glass fiber, polymeric fibrous materials).

  Both mufflers are having different construction, geometry, and principles in their application.
- The effectiveness of a reactive muffler results from the destructive interference of an acoustic waves travelling within the device. Cross sectional area changes within the device produce the interfering acoustic waves. The performance is quantified by the frequency-dependent sound Transmission Loss (Crags 1977, Song and Bolton 2000)
- The noise from the exhaust system consists of three components [1]
  - pulsation noise
  - flow generated noise coming from the orifice of the muffler outlet

™ Shell noisecoming from the shell of the muffler. Shell noise may be limited by using a stiffer or damped shell, while flow generated noise. Such as turbulence and vortex shedding may be limited by minimizing geometrical discontinuities (edges, sharp bend etc).

A reciprocating internal combustion engines are normal fitted with mufflers. The muffler fitted to an engine is intended to reduce the pressure pulses associated with the exhaust gas leaving the cylinders of the engine. Generally, mufflers fitted to such engines are essentially reactive devices as to oppose being dissipative devices. Practically reactive mufflers also have some dissipative function. An ideal muffler for reciprocating internal combustion engines functions as a low pass filter. The mean flo should be allowed to pass unimpeded through the muffler with the acoustic pressure fluctuations i minimized. If the steady flow is impeded the so-called' back pressure' will be higher and the engine will function lessefficiently. It is desirable to be able to predict the pressure drop associated with th steady flow through the muffler. Computational Fluid Dynamics (CFD) has developed over the la two decades so that this prediction can be made reliably. It is also desirable to be able to predict the acoustic performance of the muffler. Essentially this means determining as a function of frequen how harmonically varying pressure fluctuations that at inlet of the muffler are attenuated before they emerge at the outlet. The objective of this research is to model & analyze the performance of a simple expansion chamber muffler using the commercial CFD software package FLUENT [2].

1.2. Statement of the problem.

There is an increasing awareness of noise pollution on the part of the general public in urban areas, especially noise caused by automotive. A pollutant of concern to the mankind is the exhaust noise in the internal combustion engine. However is this noise can be reduced sufficiently by means of a well designed muffler. The suitable design and development will help to reduce the noise level, but at same time the performance of the engine should not be hampered by the back pressure caused b Muffler [1].

In particular, users of certain types of general automotive may be compelled to restrict operati and/or modify their automotive to comply with existing or forthcoming noise legislation that will specify upper limits on external noise levels. Analysis of this noise indicated that engine exhaust noise was the primary cause of both unacceptably high cabin noise levels and radiated far field noise [2]

1.3. General objective.

The objective of this work is to use CFD to determine the acoustic performance of a simple reactive muffler. The basic idea is to impose some level of steady flow through the muffler. CFD can be used to predict the flow variables throughout the muffler. Those of particular interest are the transmission loss, pressure and velocity at the inlet and outlet sections. The steady flow pressure wave attenuation through the muffler then can be found. The aim is to have a quiet muffler with a small pressure drop.

1.4. Specific Objective.

- Modeling expansion chamber of a simple reactive Muffler of a vehicle.
- Determining the Acoustic Performance of the Muffler using Computational Fluid Dynamics (CFD).
- Identifying basic requirements that an exhaust Muffler should satisfy to come up with an optimum Muffler Performance.
- Selecting basic criteria for the durability to withstand the high operating temperature.
- Reduce the exhaust noise generated by the internal Combustion engine using the Muffler.

CHAPTER - TWO

LITERATURE REVIEW

A lot of research work has been carried out throughout the world to investigate and analyze the noise generated by two stroke petrol engine at different loads and speeds and check the effectiveness mufflers. A brief review on few of the literature is being presented here.

Kyle Capello, Ray Francis, and Stuart McTiver [1]: - The objective of this test is to verify data from Briggs and Stratton. This is done by measuring sound power level insertion loss of various product mufflers at various load levels. Sound power level data is used to compare performance, to identify the most effective muffler, and to suggest possible areas of improvement. Six mufflers were tested on 5550 Watt Briggs and Stratton generator. The test conducted was a standard direct field sound po level test. The following conclusions can be found from the results of the test.

- ™ Each of the mufflers had a positive overall insertion loss proving that each was at lea somewhat effective at decreasing the sound power of the generator.
- ™ Each muffler had a higher insertion loss at the higher frequencies.
- ™ Some of the mufflers had a negative insertion loss at lower frequencies (i.e. <100Hz)
- ™ The low insertion loss at low frequencies was due to the noise of the generator's engine firi None of the mufflers were tuned to reduce the noise of the engine firing at 1800 rpm (30 Hz).
- ™ The best muffler of the six tested on the generator was the stock muffler (189008). Th muffler did not have the highest overall insertion loss, but at the frequencies that hum hearing is most sensitive to (~2002000Hz), the stock muffler had the best insertion loss.
- ™ The Nelson muffler did have the best overall insertion loss at all loading levels.
- ™ The focus of a redesign of the stock muffler should be on reducing the sound power at frequencies that are harmonics of the engine firing rpm (30 Hz).

Wonnacott E.J. [2] used the recommendations and established theory to analyze and build a series efficient silencers for general vehicle and stationary engine use. The recommended design proce hasgenerally been found to be flexible in its application and the silencers thus designed appear to h distinct advantages over their current counter parts in relation to design simplicity, ease of manuf and consistent attenuation performance throughout their useful life. The results of these trials are described together with details of manufacturing and testing problems that has been experience

building such units.

Priede T. [3] studied the vehicular noise subjected to varying operating conditions and it is very seldom that steady-state running occurs over a period of any length. The main operating parameters are speed, load and acceleration and deceleration, with associated gear changes. Even on a motorway where a steady speed can be maintained, the load factor of the prime mover will vary according to the road gradient. The noise of the road vehicle constitutes a number of individual sources of diverse origin and characteristic. Each of these noise sources has a different speed-related and load-related relationship and also a different transient relationship. The resultant noise therefore may have very complex characteristics. In the assessment and control of vehicle noise, and also in the determination of general traffic noise, it is essential that the effects of various operating parameters are clearly understood. These include the influence of prevailing climatic conditions which particularly affect the rolling noise. An understanding of these parameters can help to optimize road traffic environmental planning. The introduction of new products, such as turbocharged diesel engines for commercial vehicles, with different characteristics, can change considerably the characteristics of traffic noise and therefore to be fully understood and evaluated. Throughout the paper the vehicle noise and its individual sources, with particular reference to basic engine noise, are described in overall dB (A) values.

Bryce W. D. and Stevens R. C. K. [4] identified and understand the noise sources that contribute to the exhaust noise of aircraft gas turbine engines, controlled experiments have been carried out to study the noise characteristics of a model turbojet exhaust system. The noise data have been related to measurements of the aerodynamic conditions in the model and, with the aid of specific diagnostic tests, the predominant noise mechanisms are considered to have been recognized. The noise radiation, apart that of the jet, is attributed primarily to dipole sources generated by the turbine outlet guide struts, the transmission of this noise being modified by duct propagation and nozzle impedance effects.

Jha S. K. [5] studied the characteristics of noise and vibration in a motor car. The predominant frequency regions in which noise levels are high are established. It is shown that the major part of the sound energy lies within the frequency region below 20 Hz and is caused mainly by road excitation being transmitted through the wheel and suspension system. The predominant noise in the audible range lies within 30-300 Hz frequency band and is produced primarily by body resonances excited by various engine harmonics. The vibration and acoustical behavior of the car body at some of the

critical frequencies is also discussed. Finally it is shown that by structural modification substantial noise reduction can be obtained.

Oguchi Tetsuru [6] studied the piston slap noise, which is generated by the sudden impact of th piston on the cylinder wall, is the most predominant mechanical noise emitted from the engine. It studied here in terms of its transmission paths through the engine elements. Two engines with differe cylinder liners types are tested in a running condition. The transmission paths are measured and evaluated in terms of the mechanical mobility, the ratio of the velocity response on the cylinder wall to the force applied to the external surface of the engine, which represents, by reciprocity, the ratio of the velocity response on the external surface of the engine to the force applied to the cylinder wall. T work concentrates on the major transmission paths of the piston slap noise and the factors which a that transfer mobility in the frequency range of 1.5 to 4 kHz. The major transmission path of the pi slap noise is experimentally determined to be the path through the cylinder wall and the upper deck of the cylinder block to the external surface of the cylinder block.

Slack James W. [7] studied the piston slap, is typically the major source of noise and vibration in th I.C. Engine. An investigation of piston slap noise in an I.C. Engine is carried out. Vibration measurements are carried out at connecting rod, cylinder wall and block surface while monitori Drive point and transfer mobility measurements were made on a running engine. The measured mobility's are used to construct a model of piston cylinder wall interaction which predicts the excitation due to the piston slap. The measured transfer mobility's are used to predict vibration transfer to the block surface. Bending of the connecting rod is found to play an important role in both the excitation and vibration and the transmission of vibration energy to the block surface.

Cuschieri J.M. and Richards E.J. [8] studied the noise radiated from I.C. engine due to combustion and piston slap excitation is investigated by considering single impacts. From the results obtained possible method of noise control are studied, and the expected results due to changes in the mounting to the engine frame, and the bearings of the camshaft for an injected one are compared to measured noise levels. This proves to be very successful and radical modifications in the engine noise control can be investigated in this way prior to full development of the prototype Engine.

Lim M.K. and Low C.S. [9] designed an engine cylinder pressure damping device to reduce engine noise by controlling the sharp pressure rise excitation applied to the engine structure by the combu

process.The device is a small piston controlled by a spring and dashpot system concentrated to engine cylinder by mounting it on top of the cylinder head. Lab tests show that there was an insignific reduction in engine surface vibration and noise radiated, particularly at frequencies above 4000Hz.

Tandara V. [10] studied the radiator fan noise. The combustion engine is only one of many vehicle noise sources. Every combustion engine has inner and external noise sources. The cooling fans c important noise sources. They are installed to cool the engine, encasement and the inside air of the The influence of fans is great in case of high ambient temperature, low traveling speed and frequ stoppages.

Schachner P. and Reisinger W. [11] studied the concept of exhaust gas emission. The design and development of modern internal combustion engines is marked by a reduction in exhaust gas emissions and increase in specific power and torque. Correspondingly, combustion noise excitation and f consumption also have to be reduced. These objectives can be achieved through the developme advanced combustion systems, the increased flexibility of fuel injection systems. Howeve development of modern combustion systems and vehicle applications has become increasin complex. Creating an exact, yet straightforward description of combustion noise is a very important task. The customer's subjective impression of the entire vehicle, regarding items such as diesel kn sensitivity, provides evidence to support its value.

Desmons L., Hardy J. and Auregan Y. [12] applied a least squares method to characterize an internal combustion engine considered as a noise source. It is shown that, although extremely severe conditi exist (high sound pressure level, high temperatures, turbulent flow, etc.), a linear theory can be used noise level at the output of the exhaust systems with a surprisingly good accuracy when the transfe matrix is known. The measurements avoid the use of calibrated internal microphones; only o external microphone and a set of calibrated loads are needed. An indirect validation of the linearity hypothesis is achieved and the predicted exhaust noise level is compared with experimental results the case of a tube and in the case of a silencer composed of three expansion chambers.

Munjal M.L. [13] presented an overview of the research findings of the author and his students in different aspects of active as well as passive mufflers. Mufflers have been developed over the seventy years based on electroacoustic analogies and experimental trial and error.

CHAPTER – THREE

INTRODU CTION TO SOUND

Sound is a form of energy. From the source of sound this energy is propagated through the surroun medium in the form of waves. When these waves reach our ear we will have the sensation of sou Sound is a mechanical longitudinal wave. That means it needs a material medium to propagate and th particles of the medium vibrate in the direction of propagation of the sound wave.

Any source of sound (like a drum, a guitar, a tuning fork….) is always in a state of vibration. It vibrates backwards and forwards very quickly. The vibrating body (the source) produces a disturbanc in the surrounding medium. This disturbance (sound wave) travels outwards from the source [10].

3.1. Characteristics of sound.

3.1.1. Production of sound

When the source of sound vibrates it causes the molecules around it to move. These molecules can gas, liquid, or solid molecules. For example when a guitar string vibrates and if the string is continu vibrating, then the making of rarefaction and compression regions will be repeated. So a longitudinal wave will be formed. If the vibration of the string has a frequency between 20Hz and 20000Hz the compression waves are able to cause a sensation of hearing and are referred to as sound waves.

In transverse waves we measure the wavelength of the wave from crest to crest or trough to trough. But in longitudinal waves like sound, we measure the wavelength as the distance between consecutive compressions or rarefaction which is in same state of vibration, center to center or end to end. This is because in one complete vibration of the source one compression (c) and one rarefa (R) will travel forward through the air [10].

3.1.2. Transmission of sound

Sound is a mechanical wave; it needs a material medium for transmission. It is propagated by the interaction of adjacent molecules. So, denser mediums where the molecules are closer are b transmitters of sound than lighter mediums where the molecules are far apart. Solids, liquids and g transmit sound, but sound can't travel through vacuum. Sound travels fastest in solids than in liquids

and gases, because sound is a mechanical wave which is transmitted through a medium by succe molecular interaction.

3.1.3. Speed of sound in Different Media

The speed of sound depends on the material through which it is propagating. We have already seen t sound travels best through media that are dense. In a medium that has fewer molecules, thin or dense medium, sound travels with a low speed. The reason for that is as the object vibrates, in a denser medium more molecules will form the compression because there are a lot of molecules tha very close together. If sound travels well in dense medium, it means that sound will have a greater s in that medium. Thus the speed of sound is greater in solids than in liquids and greater in liquids th in gases.

Medium	Speed of sound at 0^0c (m/s)
Carbon dioxide	260
Air	331.5
Water (distilled)	1410
Mercury	1450
Iron	5130

Table 3.1. Speed of sound in different Media [12].

As we see from the table above, the speed of sound tends to increase in a denser medium. Liquid denser than gases; therefore, the speed of sound in liquids is faster that it is in gases. In the table sound has the highest speed in iron because it is the densest medium in the table. There is an exception t trend. Even though CO_2 is denser than air the speed of sound is less in CO_2 than in air.

3.1.3.1. Speed of Sound in Air

Sound is a mechanical wave. This means its speed in air depends on the number of air part transmitting the disturbance. As a result the speed of sound in air decreases with increase in altit This is because the air molecules at a high altitude are far apart, while, the air molecules at low altitude, like at the bottom of a mountain are much closer together. It follows that the closer together the molecules in the air are the higher will be the speed of sound. Another factor that affects the speed of sound in air is the temperature of the air. When the temperature of a medium increases, the kin

energy of all the molecules in the medium increases and hence the speed of sound moving through this medium will also increase. The speed of sound in air at a temperature of 0^0C is 331.5m/s. Using this and the fact that the speed of sound in air increases by 0.6m/s for every 1^0C rise in temperature, the speed of sound in air at any temperature T^0C is determined by the Equation

$$V=331.5\text{m/s}+(0.6/1^0\text{c})\ T \qquad (3.1)$$

The speed of sound in air at 24^0C is 345.9m/s.

3.1.4. Reflection of Sound-Echo.

Waves can be reflected. We know that sound is a longitudinal mechanical wave. Therefore, sound ca also be reflected like any other waves. Suppose you shout while you are some distance away fro tall building, you will hear your shout repeated. The sound waves you made hit the building and are reflected back. Therefore, the sound waves return to you and you hear your shout repeated. If sound is reflected back from an obstacle to the observer in such a way that he/she hears it distinctly a repetition of the original sound an echo is said to be produced. Note that sound waves are reflected of hard surfaces like glass and wood. Sound does not reflect off from soft surfaces like cloth and rub These surfaces absorb sound. That is why the walls of auditoriums and cinemas are covered by a soft material like curtain, to decrease the reverberation time (the time taken for sound to die a building) [10].

3.1.5. Intensity of sound

Any vibrating source can set up sound waves in air. The greater the energy of vibration, the greater the amount of energy carried by the sound wave. So, we can see that the amount of energy carried sound wave depends on the amount of energy with which the source vibrates. The intensity of so wave is defined as the rate of flow of sound energy through unit area placed perpendicular to the direction of propagation of the wave. Since energy per unit time is power, intensity can also be def as power per unit area. The SI unit of intensity is Watt per meter square (W/m^2). Because sound waves spread out at the same speed in all directions from a vibrating source; they spread out as a sphe wave front. The spherical volume around a vibrating source in a medium will be filled with the energ from the vibrating source. The area of a sphere is $4\pi r^2$. Therefore, for a point source that sends out spherical sound waves, the intensity (I) of the sound at a distance r, from source is

$$I=\frac{P}{A}=\frac{P}{4\pi r^2} \quad (3.2)$$

Where:- P= amplitude of vibration of the source.

A= the size (Area) of the source.

r= the distance from the source.

The intensity of a sound depends on the following factors:

I. Amplitude of vibration of the source. Intensity increases if the source of sound vibrates with larger amplitude. The intensity of a sound is directly proportional to the square of the amplitude of vibration. ($I \propto A^2$).

II. The size (Area) of the source. A vibrating body of a larger area sets into vibration a greater volume of the medium and thus sends out a greater amount of energy. The larger the size of the source, the intense will be the sound produced.

III. The distance (r) from the source. From equation above the Intensity (I) of the sound wave is inversely proportional to the square of the distance (r) from the source (an inverse square relationship).

Note: - The distance between the source and the listener should increase two times in order to decrease the intensity by one fourth [10].

3.1.6. Doppler's Effects of sound

The frequency of sound reaching a listener's ear will be the same as the frequency of the source when the source of sound, the medium and the listener (observer) are all at rest. If, however, the source and the observer are in relative motion, the frequency of the wave noted by the observer appears to be different from the true frequency. If you stand at a highway and an emergency vehicle approaches you with the horn blowing, the pitch (the perceived frequency) of the sound is higher as the vehicle approaches you and lower as it recedes. This happens because the sound waves which are given off by the source are being compressed (shorter wavelength) at the leading edge and they are stretched far apart (longer wavelength) at the trailing edge, this causes an apparent increase in frequency as the vehicle approaches you, and an apparent decrease in frequency of the sound, when the vehicles moves

away from you. This phenomenon of variation of the frequency of the sound heard by the relative motion of the source or the listener is known as Doppler's effort [10].

3.2. Propagations of sound waves in a reactive simple expansion chamber muffler.

Sound is a pressure wave formed from pulses of alternating high and low air pressure. These pu make their way through the air at the speed of sound. In an engine, pulses are created when an ex valve opens and a burst of high-pressure gas suddenly enters the exhaust system. The molecules in t gas collide with the lower-pressure molecules in the pipe, causing them to stack up on each other. Th in turn stack up on the molecules a little further down the pipe, leaving an area of low pressure behind. In this way, the sound wave makes its way down the pipe much faster than the actual gases do. W these pressure pulses reach our ears, the eardrum vibrates back and forth which will be interprete sound. To cancel out sound, it is possible to produce a sound wave that is exactly the opposite another wave. If two waves are in phase, they add up to a wave with the same frequency but twice amplitude. This is called constructive interference. But, if they are exactly out of phase, they add up to zero. This is called destructive interference. At the time when the first wave is at its maximu pressure, the second wave is at its minimum, if both of these waves hit ear drum at the same t nothing would be heard because the two waves always add up to zero.

The design of a resonance chamber inside a muffler reflects the sound wave which is 180 degree of phase with the Engine noise. The sound waves reflected from the wall collide with the exhau sound waves and they cancel each other out, leaving only low-level heat to emerge from the tailpipe. The resonance chamber in the muffler reflects the sound wave from the engine as it hits the reson chamber wall. As a result, destructive and constructive waves are formed inside the chamber with only a small fraction of the sound wave is released back to the atmosphere. The chamber length is care calculated to accommodate the average sound pressure level created by the engine. The exhaust are created when each cylinder in the engine is encountering an exhaust stroke, which is greatl dependant on the firing order of the engine. The more cylinders the engine has the closer the pulse created and more sound is produced [11].

CHAPTER-FOUR

INTRODUCTION TO NOISE

4.1. Introduction to Noise

In our modern world, rapidly expanding environment one of the developing problems is that of nois
Apart from the pure annoyance factor of noise, exposure to an intense sound field over a long perio
time presents the risk of permanent damage of hearing. This particular problem is becoming a sour
of serious concern to industrial corporations, trade unions and companies. The object of this part i
discuss the concept of noise, problems of noise and its effect on man and environment both as
annoyance and as a danger to health [1].

The major sources of noise are:

- Industrial noise.
- Traffic noise.
- Community noise.

Out of above three parameters, the source that affects the most is Traffic noise. In traffic noise,
70% of noise is contributing by vehicle noise. Vehicle noise, mainly, arises from two parameters i
Engine noise and Tire noise. The major concern is to study the engine noise completely that fr
where the noise is coming and analyze an engine for different speeds and loads. Loads vary from 0 to 6
kg and speed varies from 1100 to 2300 rpm [12].

- Noise: Noise is conveniently and concisely defined as unwanted sound.
- Sound: Sound waves are pressure variations produced as a result of mechanical disturbanc
  a material medium.
- Decibel: Decibel is the logarithm of a ratio of two quantities and therefore has no units
  Decibel is defined by expression as $10 \log_{10}(P/P0)$

  P is the sound pressure amplitude of the measured sound

  P_0 L V D U H I H U H Q F H [13].U H V V X U H — 3 D

Sound Pressure (N/m^2)	Sound Pressure Level(dB)	Environmental conditions.
10^2	134	Threshold of pain
10	114	Loud-automobile horn(distance 1m)
1	94	Inside subway train
10^{-1}	74	Average traffic on street corner
10^{-2}	54	Living room, typical business office
10^{-3}	34	Library
10^{-4}	14	Broad casting Studio
$2*10^{-5}$	0	Threshold of hearing

Table 4.1 Environmental conditions at different SPL[14].

4.2 Sound Sources

A distinction is made between three different types of sound sources:

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

4.2.1 Point source

A sound source can be considered as a point source, if its dimensions are small in relation to distance to the receiver and it radiates an equal amount of energy in all directions. Typical po sources are industrial plants, aircraft and individual road vehicles. The sound pressure level de dB whenever the distance to a point source is doubled[14].

4.2.2 Line source

A line source may be continuous radiation, such as from a pipe carrying a turbule

fluid, or may be composed of a large number of point sources so closely spaced that their emis may be considered as emanating from a continuous line connecting them. The sound pressure level decreases 3 dB, whenever the distance to a line source is doubled [14].

4.2.3 Plane source

A plane source can be described as follows. If a piston source is constrained by hard walls so that its power into an elemental tube to produce a plane wave, the tube will contain a quantity of ene numerically equal to the power output of the source. In the ideal situation there will be no attenua along the tube. Plane sources are very rare and only found in e.g. duct systems. When two sources radiate sound energy, they will both contribute to the sound pressure level a distance away from sources.

If they radiate the same amount of energy and the distance from the point of measurement to sources is the same, the level will increase by 3 dB compared with the level created by one sou alone[14].

4.3 Physical Property of Sound

4.3.1 Sound power

When sound is produced, a transfer of energy from the source to the surrounding air molecules t place. The rate of energy transfer is called Sound Power. The unit of Sound Power is W (Watt). audible range of sound power extends from 10^{-9} W to more than 1000W. 10 is the lowest level which can be heard by a listener close to the source, and 1000 W will create immediate hearing damage. Lower levels can also create hearing damage, if the listener is exposed for a long period of time [14].

4.3.2 Sound intensity

When a source produces sound power (P) it will create a certain Sound intensity (I) at a distance away from the source. The intensity is a measure for the amount of power through a certain area at distance. None of these units can be measured directly. Their values can, however, be calculated measurement of the sound pressure level, knowing the area over which measurements are being made.

4.3.3 Sound pressure level

Decibel (dB) is logarithmic ratio which defines the sound pressure level as follows:

$$L_p = 20\log_{10}(p/p_o) \quad (4.1)$$

P is the sound pressure measured

Po is the reference sound pressure i.e. 2×10^{-5} Pa (the threshold of hearing). Equation (4.1) applies when! (density of air) & c (speed of sound) at the inlet and outlet are the same. This logarithmic scale has several advantages over a linear scale. The most important advantages are:

1. A linear scale would lead to the use of some enormous and unwieldy numbers.
2. The ear responds not linearly, but logarithmically to stimulus.

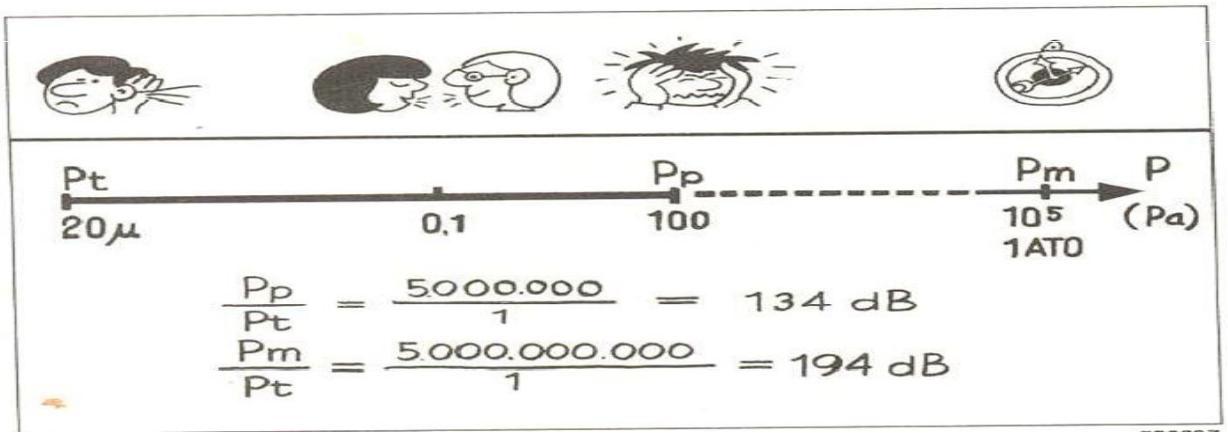


Fig 4.1 Calculation of SPL [15].

4.4. Loudness

Loudness is a subjectively perceived attribute of sound which enables a listener to order its magnitude on scale from soft to loud. It is defined as subjective intensity of sound. Based on these concepts of loudness, the phon scale was logically conceived as a measure of loudness level [15].

4.5 Some effects of noise on human beings

The following are the various harmful effects of noise on human beings [15].

1. Reduces work efficiency.
2. Affects the speech communication.

3. May cause temporary threshold shift (TTS) / permanent threshold shif (PTS).
4. Induces loss of hearing ability.
5. Causes psychological strain and mental fatigue.
6. May damage the heart.
7. Increases the cholesterol level in the blood.
8. Dilates the blood vessels of the brain.
9. Upsets the chemical balance of the body.
10. Causes headache, nausea and general feeling of uneasiness. Increases errors in motor performance.
11. Induces psychosis and acute mental agony.

4.6 Useful Applications of Noise- Noise is not only has harmful affects but sometimes it is very useful. Some of the examples when noise is useful [15].

4.6.1 Study of heart beats

Noise produced by the heart beats is very useful to diagnose the person's health accordingly [15].

4.6.2 Masking effects

Sometimes, it is necessary that nobody should hear the conversation between the two persons. For masking effect is used. For e.g., in the doctors chamber, doctor wants that nobody should hear conversation with the patient so Dr. uses masking effect by putting a more noisy exhaust fan wh make noise outside the room [15].

4.7 Noise Measuring Instrument

Noise measuring devices typically use a sensor to receive the noise signals emanating from a sou The sensor, however, not only detects the noise from the source, but also any ambient backgro noise. Thus, measuring the value of the detected noise is inaccurate, as it includes the ambient background noise. There are so many different types of instrument available to measure sound le and the most widely used are sound level meters [15].

CHAPTER-FIVE

S.I ENGINE NOISE AND MUFFLERS

5.1 Introduction of S.I Engine.

Spark ignition engines (S.I Engine) are those types of engines in which combustion of fuel takes pl inside the engine cylinder. In S.I engine, the fuel is ignited by the spark produced by spark plug. Si the combustion of fuel takes place inside the engine cylinder, so these engines are very noisy. S. engine is also known as petrol engine. According to the number of strokes per cycle, it is divided i two types[3]:

1. Two stroke engines
2. Four stroke engines

In a two stroke engine, the working cycle is completed in two strokes of piston or one revolution of crankshaft. This is achieved by carrying out the suction and compression processes in one stroke more precisely in inward stroke), expansion and exhaust processes in second stroke (or more precisely outward stroke). In four stroke engine, the working cycle is completed in four strokes of the piston two revolutions of crankshaft. This is achieved by carrying out suction, compression, expansion and exhaust processes in each stroke. It will be interesting that from thermodynamics point of view, there no difference between two-stroke and four-stroke engines. The difference is purely mechanical [3].

5.2 Engine Noise

An engine is a mechanical device that produces some form of output from a given input. An engine whose purpose is kinetic energy output from a fuel source is called a prime mover; alternatively, a motor is a device which produces kinetic energy from a preprocessed "fuel" (such as electricity, a flow of hydraulic fluid or compressed air). The various factors that contribute to the noise in engine are [3].

5.2.1 Combustion Noise

Combustion noise is produced because of unsteady combustion of fluids and it is of two types: turbulent combustion noise and periodic combustion oscillation. The turbulent combustion noise or combustion roar has no specific frequency but is composed of broad frequency spectrum. This noise is amplified if the flame is excited with the system resonance frequencies dominating. The requiremen

for reduction of this noise tend to be opposition to those for efficient combustion. Combustio oscillations involve a feedback cycle that converts chemical energy into oscillatory energy in the gas flow to the combustion region. The mechanism is such that the pressure waves generated are so pl to the velocity fluctuations. The noise spectrum involves one specific frequency and its harmonics a that frequency is related to the resonant modes of the combustion chamber. Some of the possible cure are[4]:

1. Modification of combustion chamber geometry.
2. Change of air-fuel ratio, burner type etc.
3. Change of burning rate It should be noted that combustion roar in reciprocating engin which has frequency of the firing rate is not related to the combustion noise, but is du to the gross fluctuation in the flow rate produced by periodic action.

5.2.2 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 ra where combustion noise is important. There are lots of moving parts, for example, gear, valves, rocker arms, piston and cylinder liner. Some are as follows:

1. Engine clicking noise A clicking or tapping noise that gets louder when you rev the engine is probably "tappet" or upper valve-train noise caused by one of several things: low oil pressure, excessive valve lash, or worn or damaged parts.
2. Collapsed lifter noise Worn, leaky or dirty lifters can also cause valve-train noise. If oil delivery is restricted to the lifters (plugged oil galley or low oil pressure), the lifters won't "pump up" to take up the normal slack in the valve-train. A "collapsed" lifter will then allow excessive valve lash and noise.

   I. Valve lash noise: Too much space between the tips of the rocker arms and valve stem can make the valve-train noisy, and possibly cause accelerated wear of both parts.

   II. Damaged engine parts noise: Excessive wear on the ends of the rocker arms, cam followers (overhead cam engines) and/or valve stems can open up the valve lash a cause noise.

III. Rapping or deep knocking engine noise: A deep rapping noise from the engine is usually "rods knock" a condition brought on by extreme bearing wear or damage. If the rod bearings are worn or loose enough to make a dull, hammering noise [4].

5.2.3 Piston Slap Noise

Piston slap noise is generated by the sudden impact of the piston on 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 center line, the lateral component of force on the piston changes direction, causing the piston to accelerate through the clearance and slap against the major thrust side of the cylinder wall. There are at least two piston slaps per revolution, but the major impact occurs at T.D.C. before the power stroke. These simple models do not take into account other factors which may affect the piston motion such as [4]:

- Piston pin offset.
- Rocking motion of piston.
- Frictions at piston pin as well as piston's outer surface.
- Piston configuration, especially under operation
- Pressure distribution around piston due to the squeezing motion of oil film.
- Compliance of cylinder liner wall.

5.2.4 Bearing Noise

Crankshaft bearings are always replaced when rebuilding an engine because they are a wear component. Heat, pressure, chemical attack, abrasion and loss of lubrication can contribute to deterioration of the bearings. The above features give rise to the noise. Some of the factors that cause bearing noise are as follows:

™ Dirt : Dirt contamination often causes premature bearing failure. When dirt or other abrasives find their way between the crankshaft journal and bearing, it can become embedded in the soft bearing material. The softer the bearing material, the greater

embed ability, which may or may not be a good thing depending on the size of th abrasive particles and the thickness of the bearing material.

™ Heat: Heat is another factor that accelerates bearing wear and may lead to failure the bearings get hot enough. Bearings are primarily cooled by oil flow between th bearing and journal. Anything that disrupts or reduces the flow of oil not only raises bearing temperatures but also increases the risk of scoring or wiping the bearing.

™ Misalignment: Misalignment is another condition that can accelerate bearing wear. I the center main bearings are worn more than the ones towards either end of the crankshaft, the crankshaft may be bent or the main bores may be out of alignment.

™ Disassembly Disassembly can be another cause of premature bearing failure Common mistakes include installing the wrong sized bearings, installing the wrong half of a split bearing as an upper, getting too much or not enough crush because m and/or rod caps are too tight or loose, forgetting to tighten a main cap or rod bolt specs, failing to clean parts thoroughly and getting dirt behind the bearing shell when the bearing is installed.

™ Corrosion: Corrosion can also play a role in bearing failure. Corrosion results when acids accumulate in the crankcase and attack the bearings causing pitting in t bearing surface. This is more of a problem in heavy-duty diesel engines that use high sulfur fuel rather than gasoline engines, but it can also happen in gasoli engines if the oil is not changed often enough and acids are allowed to accumulate the crankcase [4].

5.2.5. Spark Knock (Detonation).

Spark knock is a knocking, rattling or pinging noise that may be heard when the engine is accelera or is working hard under load (driving up a hill, towing a trailer, passing on the highway, etc.). S knock means the fuel is detonating. Some of the factors that cause spark knock are as follows:

1. EGR valve not working: The EGR valve is supposed to open when the engine is accelerating or lugging under a load. This allows intake vacuum to suck some exhau in through the EGR valve to dilute the air/fuel mixture slightly. This lowers combustion

temperatures and prevents knock. Inspect the operation of the EGR valve, and check a buildup of carbon deposits on the valve port that may be blocking the flow of exhau back into the engine.

2. Compression ratio too high: If an engine has been rebuilt and the cylinders have been bored to oversize, it will increase the engine's static compression ratio. Engines that supercharged or turbocharged are also at much higher risk of detonation because forced air induction system increases compression.

3. Engine overheating If the engine is running too hot because of low coolant, a cooling fan that isn't working, a plugged radiator, bad water pump, sticking thermostat, etc., may cause the fuel to detonate

4. Performance of fuel used: Regular grade gasoline is supposed to have an octane rating of 87. If the gas station or their refiner is cutting corners and the fuel is not 87, may knock[5].

5.2.6 Exhaust Noise

The engine exhaust noise originates at the exhaust tailpipe openings and is transmitted through the cabin walls, firewall, and nose gear bay. This is the loudest and most objectionable noise heard

5.3 Relation between noise, engine design and parameters

Despite the numerous exciting forces which almost simultaneously excite the engine structure. Since the gas force resulting from combustion tends to be the predominant force in most of the engines, relationship between the gas force characteristics and emitted noise can be used to establish a basis model to identify the effects of fundamental engine design and operating parameters. The three b parameters of an engine are:

™ Speed ,Size

™ load

5.3.1 Enginespeed The engine structure characteristics can be defined by use of electrodynamic vibration generators It will be seen that when the structure is subjected to a constant sinusoidal force exhibits maximum response in the high frequency range from 2000 Hz. If the engine speed is

doubled, the engine structure is now excited with lower order harmonics which have higher amplitudes.It can be concluded that the characteristics of force determine the rate of increase w engine speed [5].

5.3.2 Engine size

Measurement carried out on a large number of engines with engine size shows an increase of size to tenfold gives an increase of noise of 17.5 dB (A). The detailed investigations indicate that vibration levels of the engine surfaces are about the same irrespective of their size, thus the increase of with size is simply due to larger radiating surface area. An increase of size leads to increase of both power &operating pressure inside the engine which leads to the intensity of fluctuation to increased [5].

5.3.3 Engine load

Engine load has no effect on noise, which is in agreement with the findings that noise is simply due to the initial ignition of the fuel. This occurs at the same intensity whether the engine is running at load at all or full load. It can be concluded that [5]

1. The gas force determines the rate of increase of noise with engine speed.
2. At high engine speeds the gas force has a less significant effect on noise.

Engine noise is independent of the horse power produced.

CHAPTER -SIX

SIMPLE REACTIVE MUFFLER OF VEHICLES

6.1. INTRODUCTION TO MUFFLER .

One of the components in the exhaust system of a vehicle is the muffler. Basically, the purpose of muffler is to reduce the exhaust noise produced by the engine. The basic constructions of muffler usually consist of the tubular metal jacket, perforated tubes and the expansion chamber. The arrangement of these components will guide the exhaust gas to flow from the inlet pipe of the muffler to the outlet (tail pipe). Inside the muffler, the noise from the exhaust gas will be reduced by dissipation of the wave energy, reflection of the wave energy towards the engine or the combination of the two. Today's vehicles are equipped with two types of muffler, either the reactive muffler which consists of a number of tubular elements of different transverse dimensions joined together so as to cause, at every junction, impedance mismatch and hence reflection of substantial part of the incident acoustic energy back to the source or the dissipative muffler which consist of ducts lined on the inside with acoustically absorptive materials. Both mufflers are having different construction, geometry, and principles in their application [5].

The performance of a muffler is described by the insertion loss, Transmission loss and Back pressure. Insertion loss is defined as the difference between acoustic powers radiated without any filter and that with filter.

Transmission loss is a measure of the difference between the sound power incident (in decibel) at the entry to the muffler to that transmitted by the muffler. Transmission loss is independent of the source and presumes (or required) an anechoic termination at the downstream end.

Back pressure is the extra static pressure exerted by the muffler on the engine through restrictions to the flow of exhaust gases. An exhaust muffler is an acoustic filter except that wave's are convicted downstream by the moving medium. Inside a muffler, it contains a deceptively simple set of tubes (not in all cases) with some holes in them. These tubes and chambers are actually designed to reflect sound waves produced by the engine in such a way that they partially cancel themselves out. Most conventional mufflers are round or oval-shaped with an inlet and outlet pipe. Some mufflers contain partitions to help reduce engine noise. Generally an exhaust muffler should satisfy some basic requirements such as adequate insertion loss, low back pressure, ideal muffler sizing, and

affect the cost and accommodation and the last one could be the durability to withstand rou conditions and extremely high temperatures. Hence some design considerations have to be take order to come up with an optimum muffler design. The parameters that govern the performance of the muffler are the muffler chamber design, restrictions of the flow of the exhaust gasses and the mate of the muffler itself. The relationship between the noise and the back pressure is inverse proportional; lowering the noise level at the tip will result in high back pressure. However, this relationship is undesirable as the requirement is to have a quiet muffler with low back pressure [5].

The higher the back pressure created by the exhaust system, the less the net power available on the crankshaft and hence the more is the specific fuel consumption.

6.2. MUFFLER TYPES AND THEIR WORKING PRINCIPLES.

Mufflers are a vital part of any gasoline or diesel engine. Mufflers are expected to reduce the transmission of exhaust noise and they must do without significantly restricting the flow. A muffler is a “sound filter” and its performance varies with the frequency of sound. There are two basic types mufflers. Many mufflers used a combination of reactive and dissipative technologies. When properly designed and assembled, dissipative, reactive and combination mufflers can reduce sounds level w allowing high volumes of exhaust gasses to flow through them [5].

Multiple Baffle Mufflers: The first performance style muffler housed multiple baffles inside. This type of muffler allowed the exhaust gas to escape through holes punched through the tube. Car en noise was decreased by expansion and pulse reflection as the exhaust travelled through diffe sections of the muffler. These mufflers restrict the flow of exhaust more than others, but are st described as being reasonably quiet [6].

Turbo muffler: - The first use of the turbo muffler dates back to the 1960’s. The turbo muffler doesn contain baffles to block the flow of exhaust. This type of is manufactured with an s-shaped path inside, which allows the gas exhaust to enter into the muffler and be forced to the opposite end whe turns into a different tube to exit the vehicles exhaust system. A major drawback of the turbo muffler is the flow restriction of exhaust caused by each of the turns within the muffler. However, these tu allow the muffler to be longer on the inside than the outside, which is an advantage [5].

Straight-through muffler: - The first modern muffler also known as the straight through muffler involves the use of perforated tube. These tube forces the exhaust on the path from the inlet to outlet. There is little restriction of flow through this type of muffler. Holes are punched into the pipe to allow the gas exhaust to expand silently. A straight through muffler may possess dual chambers to allow exhaust to travel from a main tube into a second chamber. Compared to other mufflers, the straight- through type contains the best flow design[6].

Reflective Muffler: - It reflects the low frequency sound waves when the length of the expansion chambers or quarter wave resonators equals a multiple of a quarter of a wavelength.

Absorptive Muffler: -It works at mid and high frequencies by dissipating sound energy when the particle velocity of the sound waves is slowed during motion in the absorptive material. The effect of grazing flow in the perforate is limited compared to that of the absorptive material[6]. Plug flow muffler: - It works at all frequencies by dissipating sound energy when vortices at the perforate interfere with the sound field. The flow in the perforate is now mainly bias flow in opposition to grazing flow[6].

6.2.1. OPERATING PRINCIPLES OF REACTIVE MUFFLER.

Reactive mufflers, of which expansion chambers are a special case, function by causing reflected waves to be propagated back toward the acoustic source (i.e., the engine). In the case of expansion chambers, these reflected waves are generated by abrupt changes of cross sectional area. The objective in design of expansion-chamber mufflers is to arrange combinations of duct area changes in the most propitious way for reflecting acoustic energy back into the source over the desired frequency range. The simplest practical expansion-chamber muffler is shown in figure.6. It consists of two cross sectional-area changes separated by a length L. The amount of acoustic energy associated with the reflected pressure wave $p_1^{(-)}$ is a function of the cross-sectional area ratio S2/S1, whereas the length L determines the acoustic frequency at which the maximum reflection occurs [7].

Figure 6.1:- Simple expansion chamber muffler

6.2.2. PERFORMANCE OF A SIMPLE REACTIVE MUFFLER OF VEHICLES.

The ratio of fluctuating pressure wave to fluctuating volume velocity of a forward going plane wave averaged over a duct cross section through which the wave is propagating is a useful quantity describing the noise reduction performance of a reactive muffler system and is called the analogous characteristic acoustic impedance of the duct, or simply the characteristic impedance when meaning is clear from the context. At an isolated discontinuity in duct area, the change in characteristic impedance of the duct is related to the amount of acoustic energy reflected at the discontinuity. The total impedance change associated with a series of discontinuities may be calculated from appropriate boundary conditions relating fluctuating quantities across the discontinuities, or it may be determined from laboratory tests.

When all the impedance changes in a muffler system are known, the input impedance at the muffler inlet may be calculated by starting at the tailpipe and working systematically backward to the inlet. If the source impedance is known, the total radiated power of the system may be determined and compared with the radiated power before the muffler system is attached. This comparison is accomplished by taking the ratio of the radiated power before the muffler is attached to that after the muffler is attached. This ratio is called the insertion loss of the muffler system, in analogy with electrical filter theory. The insertion loss, as a function of frequency, commonly characterizes a muffler system in so far as its noise-reducing ability is concerned [8].

The acoustic performance measure: consider the simple expansion chamber muffler shown in the figure 6.2. The single frequency acoustic wave incident on the muffler has an amplitude P_i. At point 1 in the inlet pipe, this incident wave generates a wave of amplitude P_r which is reflected back along the inlet pipe, and a wave which enters the expansion chamber. Similarly at point 3, another reflected wave is produced. The wave which emerges from the muffler at point 4 and travels away from the muffler has an amplitude P_t.

The acoustic intensity associated with the incident and transmitted plane waves can be readily determined from expressions of the form $I = P^2/\rho c$, where ρ and c are the density and velocity of sound for the gas. The acoustic powers are then simply given by multiplying the intensities by the relevant cross-sectional areas. Thus the acoustic power associated with the incident wave is simply $P_i^2 S_A/\rho c$, where S_A is the cross-sectional area of the inlet pipe as shown in figure 6.2.

Figure 6.2. Simple expansion chamber muffler for impedance analysis.

Acoustic impedance means noise reduction performance of a reactive muffler. Along with the fact th at changes of cross-sectional area there must be equality of acoustic pressure and acoustic impeda across the discontinuity, enables the required acoustic pressure to be found.

The following procedure is followed at each frequency where the sound Transmission Loss is to found. At point 4 on the figure, the specific acoustic impedance in the direction shown, z_4, is equal to W K H F K D U D F W H U L V W L F L P S H G D Q F H ! F a n e c h o i c W a l k t e r m i n a t i o n . T h e W acoustic impedance at point 4, Z_4, is then given by $Z_4=z_4/S_c$. The acoustic pressures and volume velocities at points 4 and 3 are equal, and thus acoustic impedance at these points is equal. The specific acoustic impedance at point 3 is then given by $z_3=Z_3S_c$. The acoustic impedance at point 2, Z_2, is given by $Z_2=z_2/S_B$. The acoustic impedance, Z_1, and the specific acoustic impedance at point 1 are then respectively given by $z_1=Z_2$ and $z_1=Z_1S_A$.

The specific acoustic impedance at point 4 to 1 has been established. To find the acoustical pressu these points in response to an incident wave, this has pressure amplitude of unity. The complex represen tation of the acoustic pressure at point 1 needs to account for the acoustic pressure assoc with both the incident and reflected waves. Point 1 corresponds to the inlet of the expansion cham at x=0. At which the specific acoustic impedance and complex representation of the acoustic pressure are respectively given by:

$$z_4 \; ! \; \left(\frac{P_i + P_r}{P_i + P_r}\right) \qquad (6.1)$$

$$P_1 = P_i + P_r \qquad (6.2)$$

Equation (6.2) & (6.3) can be rearranged to give the complex representation of the acoustic pressure point 1 by:

$$P_1 = \frac{2P_i}{1 + \frac{\rho c}{z_1}} \qquad (6.3)$$

If the amplitude of the incident wave is unity, then the complex representation of the acoustic pressu at point 1 becomes $P_1 = \frac{2}{1 \; ! \; \frac{\rho c}{z_1}}$. Equality of the acoustic pressure at points 1 and 2 leads to $P_1 = P_2$.

6.2.2.1. Source impedance effects of muffler.

If the amplitude of the incident wave arriving at the muffler inlet from the source is equal to the amplitude of the incident wave when the muffler system is absent, then the source is said to nonreflecting and the effective source impedance is equal to the duct impedance. For reciprocating engine exhaust systems in general, this condition seems unlikely to hold for all frequencies of interest, however, experimental and/or analytical studies to date have not provided reliable information source impedance. In its absence, the muffler system designer is forced to rely on transmission loss as a measure of muffler system performance [8].

6.2.2.2. Transmission loss

Transmission loss is the ratio of the acoustic power associated with the incident wave W_{inc} to that associated with the transmitted wave W_{ave} can be used to determine the frequency dependent. It is a single number (for each frequency of interest) and does not permit the prediction of acous performance of a complete engine and exhaust muffler system. Further, transmission loss is not directly measurable and is influenced by the termination boundary condition. Its advantages are th is conceptually simple and provide a figure of merit when comparing muffler systems with identical terminations, hence the traditional propensity for its use. Also, to the extent that the source can b considered nonreflecting, the transmission loss is an indication of the insertion loss to be expecte [9].



Figure 6.3- Hybrid muffler in closed condition.

(Hybrid muffler is a combination type of muffler; it is both reactive and dissipative type.)



Figure 6.4- Hybrid muffler in cut condition.



Figure 6.5- Reflective muffler in closed condition.



Figure 6.6- Reflective muffler in cut condition.

CHAPTER-SEVEN

GENERAL DESIGN PRINCIPLES FOR AN AUTOMOTIVE MUFFLER.

7.1. Introduction.

The sole purpose of an automotive muffler is to reduce engine noise emission. If you have ever heard a car running without a muffler you will have an appreciation for the significant difference in noise level a muffler can make. If vehicles did not have a muffler there would be an unbearable amount of engine exhaust noise in our environment. Noise is defined as unwanted sound.

Sound is a pressure wave formed from pulses of alternating high and low pressure air. In an automotive engine, pressure waves are generated when the exhaust valve repeatedly opens and high-pressure gas into the exhaust system. These pressure pulses are the sound we hear. As the engine rpm increases so do the pressure fluctuations and therefore the sound emitted is of a higher frequency. All noise emitted by an automobile does not come from the exhaust system. Other contributors to vehicle noise emission include intake noise, mechanical noise and vibration induced noise from the engine body and transmission. The automotive muffler has to be able to allow the passage of exhaust gasses whilst restricting the transmission of sound [18].

7.2. MUFFLER DESIGN PRINCIPLES.

Generally automotive mufflers will have both reactive and absorptive properties. The reactive or reflective mufflers use the phenomenon of destructive interference to reduce noise. This means that they are designed so that the sound waves produced by an engine partially cancel themselves out in the muffler. For complete destructive interference to occur a reflected pressure wave of equal amplitude and 180 degrees out of phase needs to collide with the transmitted pressure wave. Reflections occur where there is a change in geometry or an area discontinuity.

A reactive muffler generally consists of a series of resonating and expansion chambers that are designed to reduce the sound pressure level at certain frequencies. The inlet and outlet tubes are generally offset and have perforations that allow sound pulses to scatter out in numerous directions inside a chamber resulting in destructive interference. Reactive mufflers are used widely in car exhaust systems where the exhaust gas flow and hence noise emission varies with time. They have the a

to reduce noise at various frequencies due to the numerous chambers and changes in geometry th exhaust gasses are forced to pass throug h.

An absorption or dissipative muffler uses absorption to reduce sound energy. Sound waves are red as their energy is converted into heat in the absorptive material. A typical absorptive muffler consis of a straight, circular and perforated pipe that is encased in a larger steel housing. Between the perforated pipe and the casing is a layer of sound absorptive material that absorbs some of the pre pulses.

Absorptive mufflers create less backpressure than reactive mufflers; however they do not reduce low as well. Generally reactive mufflers use expansion chambers that target specific frequencies to control noise where as an absorptive silencer reduces noise considerably over the entire spectrum and mo at higher frequencies. It is good practice to design a muffler to work best in the frequency range where the engine has the highest sound energy. In practice the sound spectrum of an engine exhau continually changing, as it is dependent on the engine speed that is continually varying when the car is being driven. It is impossible to design a muffler that achieves complete destructive interferenc however some will always occur.

Noise spectrum variation makes muffler design quite difficult and testing is the only sure way determine whether the muffler performs well at all engine speeds. However, as a general rule thumb, exhaust noise is generally limited to the fundamental frequency and the first few harmoni which can be calculated; therefore these frequencies should be used as a starting point for preliminary muffler design.

A practical way of determining the frequencies range to be controlled is to measure the unmuffled engine noise. This measured spectrum can then be used to identify the frequencies, at which the h noise levels occur. The high noise level frequencies should be treated with appropriate noise contro achieve an overall noise reduction. There is always more than one way to design a muffler fo specific application, however if the designed muffler is practical and achieves the required noise reduction and meets all functional requirements then the designer has succeeded [21].

7.2.1. Functonal Requirements of areactive muffler.

There are numerous functional requirements that should be considered when designing a muffler for a specific application. Such functional requirements may include adequate insertion loss, backpressure, size, durability, desired sound, cost, shape and style. These functional requirements are detailed below focusing on an automotive muffler's functional requirements [21].

Adequate Insertion Loss

The main functional of a muffler is to "muffle" or attenuate sound. An effective muffler will reduce the sound pressure of the noise source to the required level. In the case of an automotive muffler the noise in the exhaust system, generated by the engine, is to be reduced. A muffler performance or noise attenuation capability is generally defined in terms of insertion loss or transmission loss.

Backpressure

Backpressure represents the extra static pressure exerted by the muffler on the engine through the restriction in flow of exhaust gasses. Generally the better a muffler is at attenuating sound the more backpressure is generated. In a reactive muffler where good attenuation is achieved the exhaust gasses are forced to pass through numerous geometry changes and a fair amount of backpressure may be generated, which reduces the power output of the engine. Backpressure should be kept to a minimum to avoid power losses especially for performance vehicles where performance is paramount.

Every time the exhaust gasses are forced to change direction additional backpressure is created. Therefore to limit backpressure geometric changes are to be kept to a minimum, a typical example of this is a "straight through" absorption silencer. Exhaust gasses are allowed to pass virtually unimpeded through the straight perforated pipe.

Size

The available space has a great influence on the size and therefore type of a muffler that may be used. A muffler may have its geometry designed for optimum attenuation however if it does not meet the space constraints, it is useless. Generally the larger a muffler is, the more it weights and the more it costs to manufacture. Effectively supporting a muffler is always a design issue and the larger a muffler is the more difficult it is to support. A muffler's mounting system not only needs to support the

mufflers weight but it also needs to provide vibration isolation so that the vibration of the exhaust system is not transferred to the chassis and then to the passenger cabin. This vibration isolation is usually achieved with the use of hard rubber inserts and brackets that isolate or dampen vibration from the muffler to the chassis [21].

Durability

The life expectancy of a muffler is another important functional requirement especially when dealing with hot exhaust gasses and absorptive silencers that are found in performance vehicles. Overtime exhaust gasses tend to clog the absorptive material with un burnt carbon particles or burn the absorptive material in the muffler. This causes the insertion loss to deteriorate. There are, however good products such as mineral wool, fiberglass, and sintered metal composites and white wool to resist such unwanted effects. Generally mufflers are made from corrosion resistive materials.

Aluminized vs. stainless are two types of steel commonly used to manufacture muffler. Stainless steel mufflers are considered more durable and can last up to 10 years. Aluminized mild steel mufflers are prone to corrosion, and therefore they typically last around 4 years. Mild steel or aluminized steel is generally used for temperature up to 500 ^{0}C, type 409 stainless steel up to 700 ^{0}C and type 321 stainless steel for even higher temperatures. Reactive type mufflers with no absorption material are very durable and their performance doesn't diminish with time [21].

Desired sound

There has however been a growing trend in Australia in recent years for young drivers wanting to "tune up" their vehicles and this includes muffler modification. Muffler modification of a stock vehicle is generally done for two reasons being performance and sound. Vehicles leave the factory floor with mufflers generally designed for noise control not optimal performance. The standard reactive muffler is generally replaced with a straight through absorption silencer for aesthetics and to minimize backpressure and therefore improve vehicle performance.

Having exchanged the stock muffler for an absorptive type performance muffler generally means that exhaust noise is increased, leaving a noticeable deep rumble in the exhaust system. In most cases this sound is what the owner of the vehicle desires so that the public is aware of their presence. However mufflers should be designed so that exhaust noise emission is only barely audible within the passenger

cabin and the appropriate government regulations are adhered to. Breakout noise from the muffler s may be a problem and should be minimized together with flow generated noise, especially when designing a muffler for a high insertion loss [21].

Cost

A major factor in any component is the cost to the consumer. Silencers not only have to be effectiv performing their task they need to be affordable otherwise the product will fail in the marketplac Aftermarket car exhaust mufflers vary in price from $90 to $700. The cost is dependent on t materials used in the construction of the muffler, design integrity, durability and labor costs [22].

Shape and Style

Automotive mufflers come in all different shapes, styles and sizes depending on the desired application. Generally automotive mufflers consist of an inlet and outlet tube separated by a lar chamber that is oval or round in geometry. The inside detail of this larger chamber may be one numerous constructions. The end user of the muffler usually doesn't care what is inside this chamb so long as the muffler produces the desired sound and is aesthetically pleasing. It is therefore the of the muffler designer to ensure that the muffler is functional as well as marketable [22].

Possible design of reactive muffler.

There are numerous types of automotive mufflers currently in the market place and described be are the key features and benefits of various muffler designs that may be found on the vehicle. The following types of mufflers have been widely tested and the general observations from such tests described.

Automotive mufflers usually have a circular or elliptical cross section. A circular shaped cross sec is best suited in a vehicles as it delays the onset of higher order modes. Most formulas that are used predict the transmission loss of a muffler assume plane wave propagation. The properties of following designs are only valid up to the cut off frequency, where higher order modes occur. Generally for all mufflers maximum transmission loss occurs at odd multiples of a quarte wavelengths. The most basic type of silencing element that may be used for intake and exha mufflers is the expansion chamber. It consists of an inlet tube, an expansion chamber and an outlet

tubes. The inlet and outlet tubes may be coaxial known as a concentric expansion chamber or o
known as an offset expansion chamber.

Figure 7.1: Concentric Expansion Chamber

The sudden expansion and contraction in this type of muffler causes sound waves to reflect back
interfere with each other. Expansion chamber are efficient in attenuating low frequency sound
makes them ideal for automotive applications. They don't attenuate high frequency sound so well a
'beams' straight through the muffler.

Expansion chamber mufflers have been widely studied and results show that the larger the expan
ratio the greater the transmission loss. The length of the chamber should be at least 1.5 times
diameter. Similar to a standard expansion chamber is the extended inlet and outlet expansion cham
where the inlet and outlet tubes are extended into the expansion chamber. The benefit of such a design
is that part of the chamber between the extended pipe and the sidewall acts as a side branch reso
therefore improving the transmission loss. The greater the protrusion into the muffler the greater
transmission loss however the inlet and outlet tubes should maintain a separation space of at least
times the diameter of the chamber to ensure the decay of evanescent modes [22].

7.3. DESIGN OF REACTIVE MUFFLER FOR STUDY ON THE NOISE LEVEL .

7.3.1. Design of inlet pipe.

The diameter of the inlet pipe is taken same as the diameter of the exhaust port of the engine.
length of the inlet pipe is taken as small as possible so that muffler will occupy less space. There
specific procedure for designing inlet pipe of the muffler. It is designed empirically.