

Design Principles of Muffler System in Vehicle and Noise Analysis

Sarvesh A. Kulkarni¹ Rishi R. Nagare² Deep N. Nagare³ Pushkar N. Aware⁴

^{1,2,3,4}Department of Mechanical Engineering

^{1,2,3,4}Guru Gobind Singh College of Engineering and Research Centre, Nashik, India

Abstract— In today's day and age noise pollution is one of the biggest problem. With the major cause being the traffic noise. Noise pollution has hazardous effect on human health. Traffic noise from highways creates problems in surrounding areas, especially where there is high traffic volume and at high speed in traffic noise, the major causes of noise are vehicle. In this paper we will learn how muffler helps in efficient noise cancellation in vehicle. And will give a better idea on importance of muffler's use.

Keywords: Traffic noise; high traffic volume

I. INTRODUCTION

In an internal combustion engine, the exhaust gases that emanates out of the exhaust port, produces sound waves of high intensity in a way that it creates noise of undesired amounts [1]. The burning of the fuel air mixture in the cylinders can be almost compared to a timely explosion within the cylinder. These acoustic waves have to be properly attenuated to recommended levels as per the jurisdictions of the respective country's government under which this engine is licensed to run.

The exhaust muffler is basically a device that contains multiple expansion chambers, diffluent holes, perforated pipes, extended tub resonators, baffles or reflecting plates, sound absorbing materials etc. [2]. as shown in Fig 1. all housed and dimensioned optimally to attenuate the noise within the Benchmarked frequency range in consideration. The flow within the muffler or the interior design, determines the pressure drop, velocity, noise reduction, transmission loss, insertion loss, etc. within the muffler. The muffler would use a combination of the principles of resonance; reflect ion, absorption, expansion etc. to meet its intended purpose [3].

Noise control is becoming increasingly important for a wide variety of OEM designers. Examples of products that take noise control considerations into account during their design cycles include equipment such as computer hard drives, house appliances, material handling and transportation equipment etc.,. In the transportation market, which includes aircraft, ground and marine segments, the demand is for low noise level goals. Achieving these goals is of primary importance for OEM to be continuing to be competitive or to keep a given supremacy in the market. The automotive industry has been a leader in the adsorption of noise control technologies. Methods in use for several years for the prediction of interior noise levels include: finite element method (FEM), statistical energy analysis (SEA) boundary element analysis (BEA) etc. The internal combustion engine has mechanized the world. Since the early 1900s it has been our prime source of mechanical power.

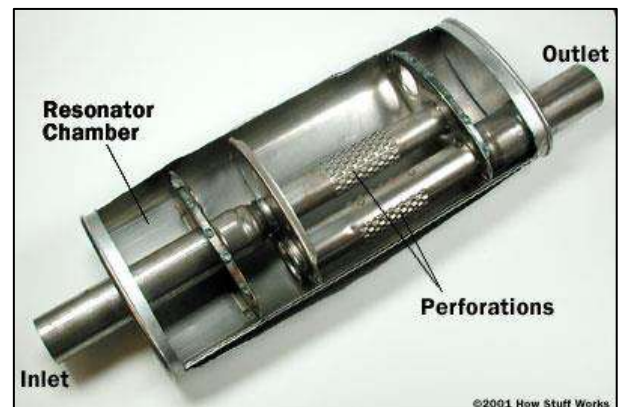


Fig. 1: Internal design of Muffler

The vast number of internal combustion engines in the world today has resulted in air pollution, noise pollution. With an increasing number of vehicles, the reduction of traffic noise emissions becomes a greater social requirement. On the other hand, as users tastes for motorcycles have diversified, it becomes important to develop and supply products to meet customers' requests within a short period. Therefore, it is a key factor to efficiently develop motorcycles which conform to the noise regulations. This paper describes concrete examples of currently utilized noise-source proving methods and noise reduction methods for motorcycle.

Noise Control guidelines are primarily intended to be used by municipal officers to assist in the resolution of complaints or to avert a possible noise nuisance. Some guidelines have been prepared so that they could be incorporated into a permit condition of a development or embodied as a local law. The guidelines are designed, however, to be the basis of assessment and not the last word. Many of the guidelines do not require an actual measurement of the noise. In these cases, the inherent nature of the activity outside of the hours suggested is sufficient to consider the activity unreasonable. EPA appreciates feedback on issues where additional noise control guidelines are considered useful or where refinements to existing guidelines are considered necessary.

Note: These guidelines are a reproduction of the former EPA publication TG302/92. The publication has been updated to reflect regulatory changes under the Environment Protection (Residential Noise) Regulations 2008 and to address queries raised through consultation for these regulations. The sections for fixed domestic plant; for construction and demolition site noise and for noise assessment have been updated, and the ordering of sections has been changed. Other minor amendments are:

- A requirement for waste collection has been added
- References and standards for aircraft noise, scare gun noise and noise from shops have been updated.

Exhaust noise is one of the major contributors to noise from vehicles powered by internal combustion engine. For the same power rating, diesel engines are noisier than gasoline engines, since the combustion characteristics of

diesel engines produce more harmonics than slower combustion of gasoline. An unmuffled gasoline engine radiates exhaust noise in the range from 90 to 100 dBA while an unmuffled diesel engine under identical conditions radiates exhaust noise in the range from 100 to 125 dBA. The suppression of engine exhaust noise has been a subject of interest for many years. Fortunately, however, this noise can be reduced sufficiently by means of a well-designed muffler. The muffler is an important component of the modern vehicle exhaust system. In order to comply with the law of environmental protection, the exhaust of vehicle including the noise and the burned gas should be strictly controlled. Thus muffler design becomes more and more important in noise reduction. In general two types of mufflers are in use [4]. Dissipative muffler and reactive muffler.

II. DESIGN PRINCIPLES OF MUFFLER

A car engine generates high intensity pressure waves transmitted through the exhaust pipe and radiated to the environment. The frequency of the generated pulse recurs at the firing frequency of the engine, given as $f = (\text{engine rpm} \times \text{number of cylinders}) / 120$ for a four-stroke engine. The exhaust noise frequency is subjugated by a pulse at the firing frequency as well having a broadband module in its spectrum which widens to higher frequencies. Exhaust pipe pressure pulse measurements on a car engine show that the majority of the pulse energy lies in the frequency range of 0–600 Hz.

Exhaust mufflers are designed to reduce the sound levels at these frequencies. The sound waves propagating through a pipe can be soothed using either a dissipative or reactive muffler. Sound absorbing materials have been used in dissipative mufflers for taking energy from the acoustic motion of the wave during its propagation through the muffler. Generally, reactive silencers used in automobiles replicate the sound waves back towards the source and prevent sound from being sent out of the pipe. The design of reactive silencers is either based on the principle of a Helmholtz resonator or an expansion chamber, which further requires the use of acoustic transmission line theory. A cavity is added to the exhaust pipe during the design of a Helmholtz resonator. The cavity will resonate at a particular frequency, and the waves in the exhaust pipe are returned back towards the source. According to some designers, the muffler has a number of resonators of different sizes to target a range of frequencies. Due to sudden changes in the cross-sectional area in the pipe, the expansion chamber mufflers reflect the waves, which have a broadband frequency characteristic but do not have the high attenuation of the Helmholtz resonator. The tailpipe length has significant role in muffler design, which acts as a resonant cavity that links with the muffler cavity. The effect of exhaust gas flow speed has a detrimental effect on muffler performance. According to Beranek and Istvan (1992), the muffler attenuation can be decreased from 35 dB to 6–10dB as the flow speed increases from 0 to 230 ft/sec.

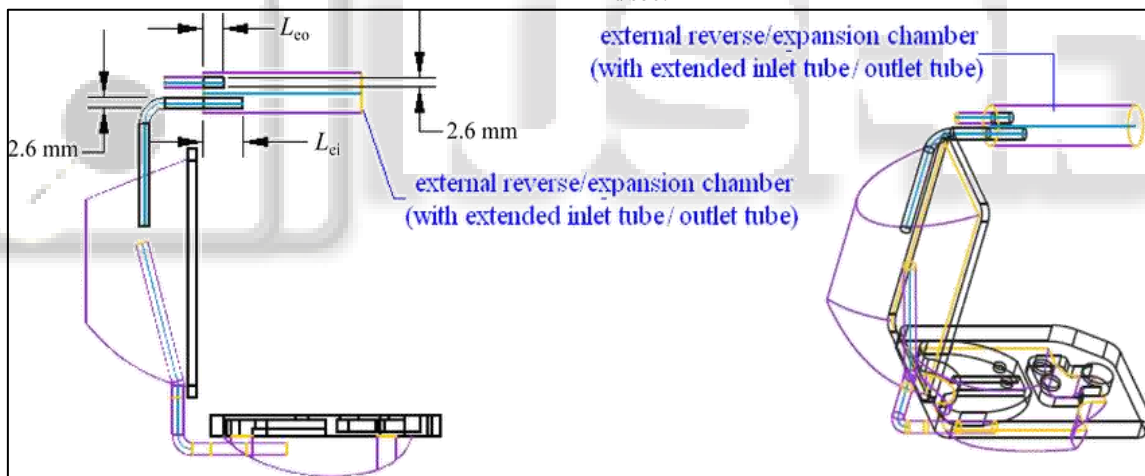


Fig. 2: Design Principles of Muffler

III. WHERE DOES THE SOUND COME FROM?

Sound is a pressure wave formed from pulses of alternating high and low air pressure. These pulses make their way through the air at -- you guessed it -- the speed of sound.

In an engine, pulses are created when an exhaust valve opens and a burst of high-pressure gas suddenly enters the exhaust system. The molecules in this gas collide with the lower-pressure molecules in the pipe, causing them to stack up on each other. They 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.

When these pressure pulses reach your ear, the eardrum vibrates back and forth. Your brain interprets this

motion as sound. Main characteristics of the wave determine how we perceive the sound:

Sound wave frequency - A higher wave frequency simply means that the air pressure fluctuates faster. The faster an engine runs, the higher the pitch we hear. Slower fluctuations sound like a lower pitch. Air pressure level - The wave's amplitude determines how loud the sound is. Sound waves with greater amplitudes move our eardrums more, and we register this sensation as a higher volume.

IV. HOW CAN YOU CANCEL OUT SOUND?

The key thing about sound waves is that the result at your ear is the sum of all the sound waves hitting your ear at that time. If you are listening to a band, even though you may hear several distinct sources of sound, the pressure waves hitting your ear drum all add together, so your ear drum only feels

one pressure at any given moment. Now comes the cool part: It is possible to produce a sound wave that is exactly the opposite of another wave. This is the basis for those noise-canceling headphones you may have seen hit your ear drum at the same time, you would not hear anything because the two waves always add up to zero.

V. ANALYSIS

There is lot of theories on how sound waves Go forth and the path that sound waves displaces through mufflers, but can inscribe how formulas are used in pointing the chambers and tubes inside the muffler. Channels and chambers of a muffler are created for a reason. Some sound waves are eliminated and others are opened to pass through. The most effective thing is that others find in an automobile the right way is the sound that the bike creates. Formulas used in pointing certain sound frequencies are mostly based on the number of cylinders of the engine and the cylinder firing order of the engine that a researcher is designing silencer for. Internal design relay on volume. Both the sum of space that is open in the space and the volume of the muffler want for the engine size and rpm are a must in calculating where channels and baffles have. Each type of muffler has its design formulas and physics theory to acknowledge and to when designing a muffler for a new application.

A. Boundary conditions given for the analysis:

Entry Mass flow rate at 1500RPM = 0.0297732456905 Kg/S

Entry Mass flow rate at 7500RPM = 0.148866234525 Kg/S

Exit pressure = Atmospheric Pressure (1Bar)

VI. RESEARCH REVIEWS

In 2005, M. Rahman et al. designed and constructed a muffler for reducing noise level. The muffler was designed for a stationary petrol engine and various noise performance characteristics were experimentally analysed and compared with that of the conventional muffler. The low frequency noise waves are emanated off by the side branch resonator. In order to use the muffler with different engines there is tuneable resonator accommodated within the muffler. Both the high and low frequency noises can be attenuated by the proposed muffler. The resonator has a working bandwidth of 110Hz, so if the residual frequency exceeds the range of this bandwidth, the resonator becomes largely ineffective [9].

M.C. Chiu and Y.C. Chang in their paper on muffler designing, published in 2011, explains their researches on side inlet or outlet type mufflers that has perforated tubes which are open ended.

The designing is done using simulated annealing. In conjunction with a simulated algorithm, a 4-pole matrix system is derived in order to calculate the acoustic performance. They concluded that mufflers with perforated tubes that intrude from expansion chamber to chamber is superior in performance of attenuation to a non-perforated tube. They showed that perforated or non-perforated open ended tube incorporated multi-expansion chamber mufflers together with surface algorithm optimizer can be efficiently incorporated or optimized into the given limited space using a 4-pole transfer matrix, plane wave theory and a technique of decoupling that is generalized.

They found that a three chambered non perforated intruding pipe muffler and a two chambered perforated tube muffler possesses the same noise reduction capacity, showing us that perforated tubing's has more to do with noise attenuation[10].

In 2010, Shital Shah et al. explained in their paper about the proper and systematic steps involved in designing, developing and prototyping of exhaust muffler and its validation which will give advantages over the conventional method which will shorten the cycle time for product development and its validation[10].

Jin Woo Lee and Gang-Won Jang in their paper published in 2012, focuses upon designing topology for improving noise attenuation of muffler and betterment of characteristics of flow, without creating much resistance to flow for improving transmission loss. So they have formulated a problem of multi-objective for optimization of topology, with an intension of maximizing the transmission loss and minimizing the backpressure. The sum of the weighted TR and weighted backpressure or pressure drop is the functional objective in the formulation. Finally, in conclusion they could arrive at an optimal topology based design where they have carefully increased the weightage of minimizing the pressure drop without giving of the transmission loss. The advantage is that this could be applied to non-concentric muffler internal orientations too. It was found way better than the initial muffler design that was based on a single objective of increasing the transmission loss for obtaining maximum noise attenuation [11].

In 2013 Tachung Yang and Sheng-Shian Tsai came with the idea of designing an optimal muffler with Taguchi method. Their experiments were done for a Roots blower of 40HP. They used blankets of fibre glass with different densities inside the chamber to reduce the high frequency noises and plates or sheets with micro perforations and chambers with multiple resonance with the intension of minimizing the noise by low to medium range of frequencies. They could get a good noise reduction of 33dBA. The design they concluded. ANOVA analysis was done on the acoustic simulation results in finding performance and the sensible factors in designing. The best Combination of these sensible factors was obtained by the S/N ratio and curves of S/N obtained by Taguchi method. In conclusion this work is more of an approximation to optimal designing and only a single frequency is considered. Considerations for a wide frequency range has to be done Further. Improvements can be obtained by using multi objective optimizations and surface methodology responses for better design factor values and design optimization [12].

In 2014, Rahul D. Nazirkar et al. designed and optimized an exhaust muffler which has a working frequency different from the natural frequency so as to avoid resonance and hence reduce the noise. The solid modelling of exhaust muffler is created by CATIA-V5 and modal analysis is carried out by ANSYS to study the vibration and natural frequency of muffler. They conclude that Double expansion chamber gives better results as compared to single expansion chamber and that transmission loss of the muffler can be increased by adding protrusion pipe at inlet and outlet [13].

VII. APPLICATIONS

Mufflers are used mainly to dissipate the loud sounds created by the engine's pistons and valves. Every time your exhaust valve opens, a large burst of the burnt gases used during your engine's combustion is released into the exhaust system. This release of gases creates very powerful sound waves.

VIII. CONCLUSION

This research paper discussed about the effective ways in Noise Cancellation and reduction by use of muffler system in vehicle. And also explains the research works done by several author/ authors. The designs they have found the most suited for the particular engine or device they have worked on and the methods they used to arrive at that conclusion is understood. Several principles and theories or methodologies to be used while designing an exhaust muffler is well explained in all the research works, which gives a greater understanding of designing a muffler.

REFERENCES

- [1] U.-C. Jeong, J.-S. Kim, Y.-D. Kim, and J.-E. Oh, "Noise reduction of the automobile multimode muffler using differential gap control and neural network control," *Proc. Inst. Mech.*
- [2] *Eng. Part D J. Automob. Eng.*, vol. 230, no. 7, pp. 1–14, 2016.
- [3] T. Yasuda, C. Wu, N. Nakagawa, and K. Nagamura, "Predictions and experimental studies of the tail pipe noise of an automotive muffler using a one dimensional CFD model," *Appl. Acoust.*, vol. 71, no. 8, pp. 701–707, 2010.
- [4] a a K. Mohammed Ali, Y. D. Ali, and R. K. Jassim, "Using the swirl phenomenon in automotive engine mufflers," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 221, no.7, pp. 837–843, 2007.
- [5] Bell L. H., *Industrial Noise Control*, Marcel Dekker Inc., New York , 1994.
- [6] *Automobile engineering-volume 2* (Rd. Sirpal Singh).
- [7] AMA (American Motorcyclists Association-2009).*Exhaust System Sound Emissions Ordinance*. Pickerington, OH.
- [8] M. Rahman, T. Sharmin, A. F. M. E. Hassan, and M. Al Nur, "Design and Construction of a Muffler for Engine Exhaust Noise Reduction," *Proc. Int. Conf. Mech. Eng.*, vol. 2005, no. December, pp. 28–30, 2005.
- [9] M.-C. Chiu and Y.-C. Chang, "Optimal Design of Side-Inlet/Side-Outlet Expansion Mufflers with Open-Ended Perforated Tubes Using Simulated Annealing," *J. Mech.*, vol. 27, no. 4, pp. 533–544, 2011.
- [10] S. Shah, S. Kuppili, K. Hatti, and D. Thombare, "A Practical Approach towards Muffler Design, Development and Prototype Validation," *SAE Int.*, no. January, pp. 1–16, 2010.
- [11] J. W. Lee, "Optimal topology of reactive muffler achieving target transmission loss values: Design and experiment," *Appl. Acoust.*, vol. 88, pp. 104–113, 2015.
- [12] T. C. Yang and S. S. Tsai, "Design Optimization of an Industrial Muffler by Taguchi Method," *Adv. Mater. Res.*, vol. 871, pp. 277–282, 2013.
- [13] R. D. Nazirkar, A. D. Namdas, S. U. Navagire, and S. S. Devarshi, "Design & Optimization of Exhaust Muffler &," pp. 31–37, 2014.