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Experimental Analysis of Reactive Silencer

#1Akshay Gopal Doijode, #2Prof. (Dr.) S. Y. Gajjal

1Akshay.doijode@gmail.com

#1M.E. (Mechanical Design Engineer), NBNSSOE,Ambegaon, Savitribai Phule Pune University, Pune, India,
#2Professor, Department of Mechanical Engineering, NBNSSOE,Pune3, India

ABSTRACT

Combustion process in the I.C. engines and exhaust process produces gaseous pollutants as well as acoustic pollutants. The pulsating flow from each cylinder's exhaust process of automobile engine sets up pressure waves in the exhaust system having average pressure levels higher than the atmospheric. The pressure waves propagate at speed of the sound relative to the moving exhaust gas, which escapes with a high velocity producing an objectionable exhaust noise. A suitably designed exhaust muffler accomplishes the muffling of this exhaust noise.

***Keywords*— engine, Acoustic, Experimental, Reactive Muffler,Analysis**

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I. INTRODUCTION

Internal combustion engines are typically equipped with an exhaust muffler to suppress the acoustic pulse generated by the combustion process. A high intensity pressure wave generated by combustion in the engine cylinder propagates along the exhaust pipe and radiates from the exhaust pipe termination. The pulse repeats at the firing frequency of the engine which is defined by f = (engine rpm x number of cylinders)/120 for a four stroke engine. A pulse at the firing frequency dominates the frequency content of exhaust noise, but it also has a broadband component to its spectrum, which extends to higher frequencies. Measurements of the exhaust pipe pressure pulse on a Continental O-200cc engine show that the majority of the pulse energy lies in the frequency range of 0-1800 Hz. Exhaust mufflers are designed to reduce sound levels at these frequencies.

In general, sound waves propagating along a pipe can be attenuated using either a dissipative or a reactive muffler. A dissipative muffler uses sound absorbing material to take energy out of the acoustic motion in the wave, as it propagates through the muffler.

Reactive silencers, which are commonly used in automotive applications, reflect the sound waves back towards the source and prevent sound from being transmitted along the pipe. Reactive silencer design is based either on the principle of a Helmholtz resonator or an expansion chamber, and requires the use of acoustic transmission line theory.

In a Helmholtz resonator design a cavity is attached to the exhaust pipe. At a specific frequency the cavity will resonate and the waves in the exhaust pipe are reflected back towards the source[3]. However there are also pass band frequencies where the resonator has no effect and so resonator muffler design is targeted to specific frequencies where the majority of the attenuation is required. In some designs, the muffler has several resonators of different sizes to target a range of frequencies.

Expansion chamber mufflers reflect waves by introducing a sudden change in cross sectional area in the pipe. They do not have the high attenuation of the Helmholtz resonator, but have a broadband frequency characteristic, with pass bands when half the acoustic wavelength equals the cavity length. Their performance also deteriorates at higher frequencies when the cross axis dimension of the muffler is 82% of the acoustic Wavelength. Some expansion chamber muffler systems are also packed with sound absorbing material, which helps to improve the high frequency attenuation.

In all muffler designs the tailpipe length can have an important effect. The tailpipe itself acts as a resonant cavity that couples with the muffler cavity. The attenuation characteristics of a muffler are modified if the design tailpipe is not used. Also, the effect of exhaust gas flow speed has a detrimental effect on the muffler performance. In typical industrial or diesel truck engine applications the exhaust flow speed can be 164 ft/sec to390 ft/sec. The effect of flow is related to the interaction of sound with turbulence and will be dependent on the internal design of the muffler.

Need of a mufflers

Mufflers are used to reduce the combustion noise present at the exit of the exhaust. As the noise norms becoming more stringent, it's necessary for the entire automotive manufacturer to give more attention in the design of mufflers. Designing mufflers have been a challenging task for the designer for many years as it is not only reducing the noise but it also creates backpressure, which reduces the overall efficiency of the engine. Noise creates annoyance, sleep disturbance and if it is too loud then it can damage our hearing capability. Hence it is necessary to install muffler in every automotive so that noise emission can be controlled and remain within the noise norms.

Mufflers

Generally speaking, there is no technical distinction between the silencer and muffler, and the terms are frequently used are inter changeable. Silencer has been the traditional name for the noise attenuating device, while a muffler is smaller, mass produced device design to reduce the engine exhaust noise.

A muffler is a device for reducing the amount of noise emitted by a machine (I C engine). As the noise norms becoming more stringent, it's necessary for the entire Automotive manufacturer to give more attention in the design of mufflers. Designing mufflers have been a challenging task for the designer for many years as it is not only reducing the noise but it also creates backpressure, which reduces the overall Efficiency of the engine. Noise creates annoyance, sleep disturbance and if it is too loud then it can damage our hearing capability. Hence it is necessary to install muffler in every Automotive, so that noise emission can be controlled and remain within the noise norms.

Requirements of an engine exhaust muffler

- Adequate insertion loss: The exhaust muffler is designed so that muffled exhaust noise is at least 5 dB lower than the combustion-induced engine body noise or other predominant sources of noise like transmission noise in earth-moving equipment. Frequency spectrum of unmuffled exhaust noise is generally required for appreciation of the frequency range of interest, although it is well known that most of the noise is limited to the firing frequency and its few harmonics.
- Size: A large muffler would cause problems of accommodation, support (because of its weight) and of course excessive cost price.
- "Breakout noise from your muffler shell must be minimized".
- The muffler performance must not deteriorate with time.
- Flow-generated noise within muffler element and at the tail pipe exit should be sufficiently low, particularly for mufflers with large insertion loss.
- Spark-arresting capability is also a requirement occasionally (particularly for agricultural use).
- Back pressure: It should be as minimum as possible.

Types of mufflers

Despite the terms and myriad of configurations, the silencer can be broken into three fundamental types: 1.Absorptive (dissipative), 2. Reactive or Reflective and 3.combination of Reactive and absorptive. In addition to the three main silencer types, other functionality such as spark arresting, emission control, heat recovery, etc., may also be incorporated into the silencer design. Each type of silencer has specific performance attributes that can be used independently or in combination to produce the required IL for a specific application.

II. REACTIVE MUFFLER

Reactive silencers generally consist of several pipe segments that interconnect with a number of larger chambers. The noise reduction mechanism of reactive silencer is that the area discontinuity provides an impedance mismatch for the sound wave traveling along the pipe. This impedance mismatch results in a reflection of part of the sound wave back toward the source or back and forth among the chambers. The reflective effect of the silencer chambers and piping (typically referred to as resonators) essentially prevents some sound wave elements from being transmitted past the silencer. The reactive silencers are more effective at lower frequencies than at high frequencies, and are most widely used to attenuate the exhaust noise of internal combustion engines. A generic reactive engine silencer comprised of proportionally sized chambers with a pair of interconnecting tubes is shown below.

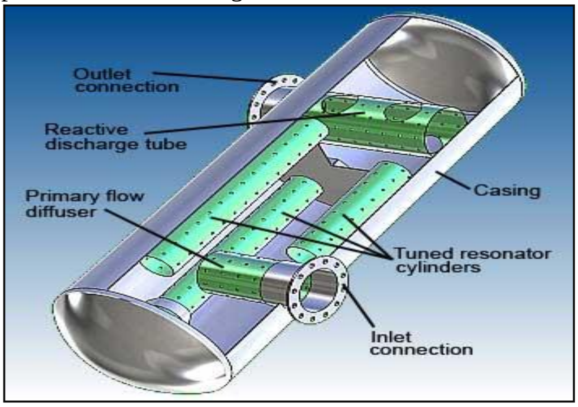

Fig.1 Reactive muffler [9]

Many terms are used to define the working of any reflective mufflers. These terms are very important to completely understand the working of muffler.

- Impedance:

The term impedance is used for the resistance of a system to an energy source. For constant signal, it usually constant. For varying signal, it's usually change with frequency.

- Acoustic impedance (z):

It's a frequency dependent parameter and is very useful. Mathematically,

$$Z = p/(v*s)$$

Where,
P = sound-pressure,
V = particle velocity,
S = Surface area

➢ Characteristic impedance (Zo):

It's a material property of a medium such as air, rock or water. Mathematically,

$$Zo = \rho * C$$

Where,
ρ = Density of the medium
C = velocity of sound

Muffler performance parameters

As per the literature and statistical survey, the required silencer volume for better performance is 8 –10 times the engine capacity.The use of an exhaust silencer is prompted by the need to reduce the engine exhaust noise. In most applications the final selection of an exhaust silencer is based on a compromise between the predicted acoustical, aerodynamic, mechanical and structural performance in conjunction with the cost of the resulting system.

Sound transmission characteristic of a structure can be measured in terms of the one ofthe following parameters

1) Insertion loss, IL

2) Transmission loss, TL

3) Level difference LD, or noise reduction, NR

i) Insertion loss (IL)

Insertion loss is defined as the difference between the acoustic power radiated without the structure and that with the structure. Symbolically,

$$IL = 10 \log \frac{W_1}{W_2} \text{ dB}$$

where W1 and W2 denote the acoustic power without the structure and with the structure.

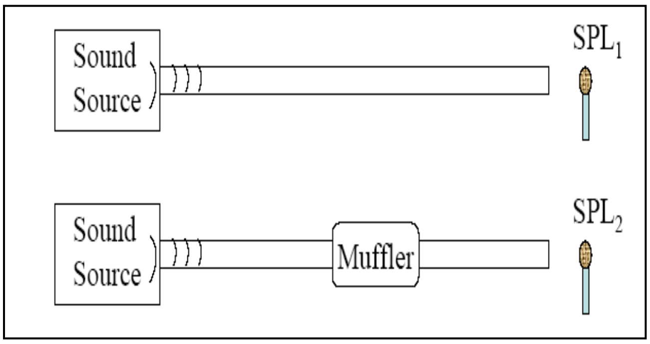

Fig.2 – Concept picture of Insertion Loss

ii) Transmission loss (TL)

Transmission loss is defined as the ratio of the incident power and transmitted powerfrom the structure. Symbolically,

$$TL = 10 \log \frac{W_i}{W_t} \text{ dB}$$

Where Wi and Wtdenote the incident acoustic power and transmitted acoustic power. TLis used in this work to evaluate the performance of the muffler wall.

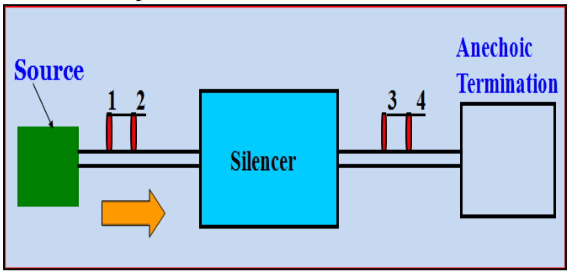

Fig.3 Concept picture of Transmission Loss

3) Level difference (LD)

Level difference LD, or noise reduction, NR is the difference in sound pressure levels attwo arbitrarily selected points inside the structure and outside the structure. Symbolically,

$$LD = 20 \log \frac{P_i}{P_o} \text{ dB}$$

Where Pi and Po denote the pressure inside the structure and outside the structure.

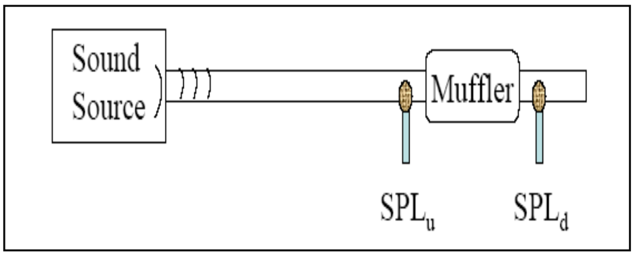

Fig.4 Concept picture of Level difference

4) Back Pressure:

The average pressure in the exhaust pipe during the exhaust stroke is called the mean ambient pressure; and the term "back pressure" is used to denote the difference between this and the ambient pressure.

This back pressure is due to loss in stagnation pressure in various tubular elements and across various junctions. When this back pressure is low enough (less than .1 bar), it simply represents a corresponding loss in the in brake mean effective pressure (BMEP) of the engine.

III.EXPERIMENTAL SETUP

A schematic diagram of experimental set up for calculating TL of SEC is as shown in figure. It consists of a noise generation system, noise propagation system and noise measurement system. The TL is measured by transfer function method . The set has following main components,

- Impedance Tube
- Data acquisition system
- Noise source with amplifier
- Sound pressure measuring microphones

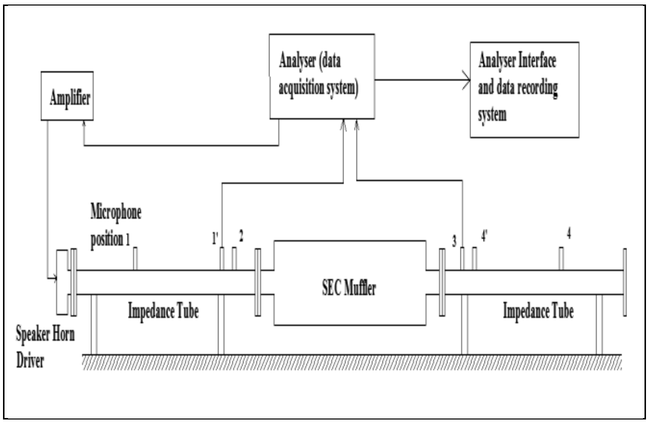

Fig.5 Experimental set up with its components

Impedance tube is a rigid tube through which sound propagates and reflects from test sample which results in creation of standing waves in it. It has measuring locations at specific distances from test sample where the acoustic pressure is measured. A sound source device is connected at the one end of impedance tube and test muffler at other end. As we are interested in incident and transmitted wave, two impedance tubes are used either side of the muffler. The main purpose served by impedance tube is providing guidance to sound wave as required for plane wave propagation.

The data acquisition system used is a 4 channel FFT analyzer with an interface package called NV Gate V7.0 for the control and setting of analyzer. It collects the pressure data from microphones and feed it to data recording storage system. It also has a single output channel which fed to speaker through analyzer. A random noise signal is generated in analyzer and play by the speaker. The reason behind using random noise is it contains equal power density of noise for each frequency. Sound source used is of high wattage to produce at least 120 dB of noise. Pressure field microphones are used for measurement. The two microphones are sufficient as transfer function method is used. Transfer function is evaluated for each set of reading. The actual test set up with as component specifications is as shown in figure. Two configuration of set up is used with respect to end conditions here shows one configuration of no load condition.

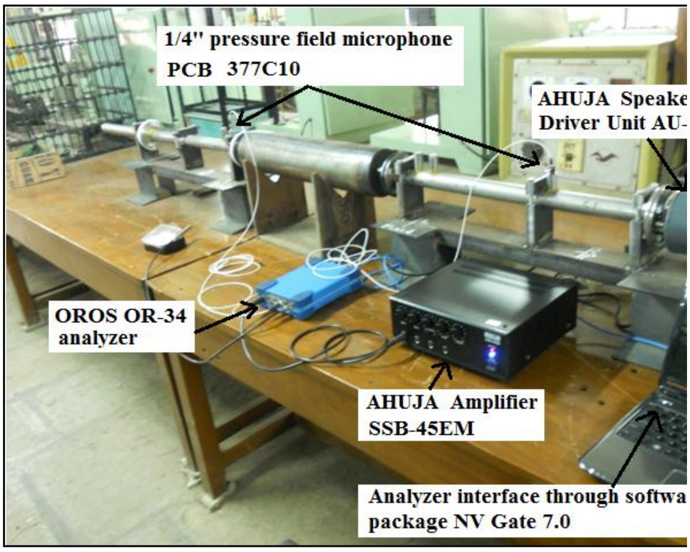

Fig.6 Actual experimental set up

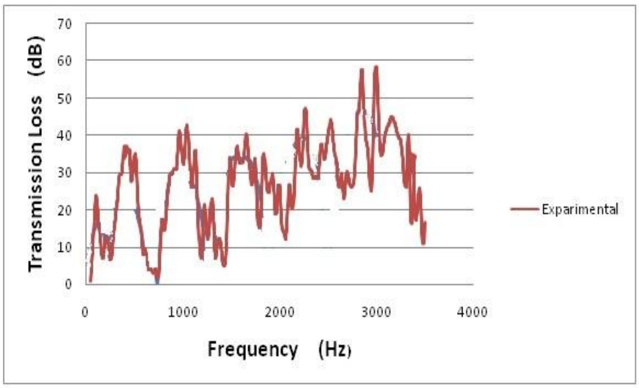

Fig.7 Experimental result of Simple Expansion Chamber with centrally located baffle with single hole

IV. EVALUATE TL FOR SIMPLE EXPANSION CHAMBER WITH CENTRALLY LOCATED BAFFLE WITH SINGLE HOLE

A. Muffler In SYSNOISE By BEM:

SYSNOISE is an FEM/BEM based computational acoustics program that allows users to input a geometry, impose boundary conditions, select environmental parameters, and solve the system of resulting equations in one, two or three dimensions. Once the system has been solved, a host of post-processing options are available to determine the various performance characteristics. Using command line code, it was possible to perform the calculations for all three methods, utilizing both FEM and BEM, and in both two and three dimensions.

i. Analysis in SYSNOISE by BEM:

A typical TL calculation using SYSNOISE has the following steps

Model-1 – Acoustic Harmonic BEM

- Mesh on surface only
  - field-point mesh for other results
- Direct BEM solver
  - closed geometry
  - fluid on one side: interior or exterior
- Indirect BEM solver
  - no restriction on geometry
    - open
    - ribbed
  - fluid on both sides: interior and exterior
- Surface absorbers

ii. Principle Steps of Boundary Element Application:-

- Model Definition
  - Meshes
  - Model Type
  - Acoustic Properties
  - BC: source, vibrating panels
  - Advanced Boundary Conditions
- Use of BEM solvers
- BEM applications
- Post processing

Calculation of TL:

It is a reasonable speculation that the frequency at which the TL would be maximum is at the acoustic modes of muffler. The analysis is an integral step during the calculation of TL using BEM. The acoustic modes of the muffler could be obtained by performing a BEM analysis in

SYSNOISE. Acoustic finite element analysis is not a part the boundary element analysis, which is used to calculate the TL. This analysis is performed only to obtain a better understanding of the system behavior. The acoustic FLUID boundary element analysis consists of the following steps.

- Mesh the acoustic cavity in HYPERMESH
- Import the FE model to SYSNOISE
- Assign the properties of air to the mesh
  Mass density = 1.225 kg/m3
  Sound velocity = 340 m/sec
- Apply impedance boundary condition on the open faces using the equation

$$Z = \rho c(0.24(ka)^2 + j(0.56ka))$$

$$k = \frac{2\pi f}{340}$$

a= radius of pipe

Solve the model to obtain the results.

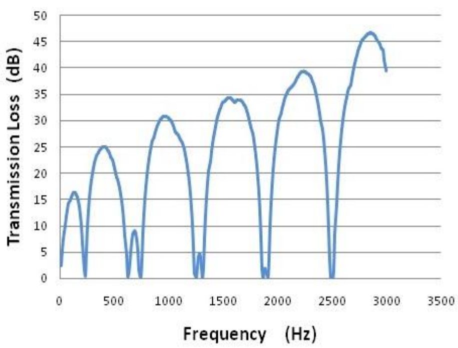

Fig.8 Simulation results of Simple Expansion Chamber with centrally located baffle with single hole.

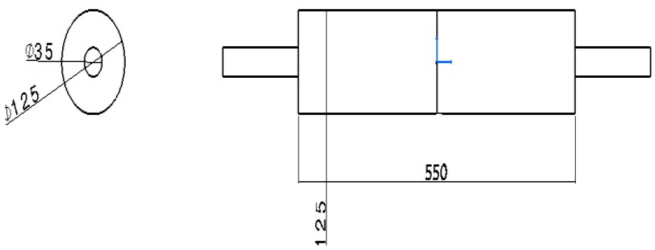

Fig.9 Model of simple expansion chamber with centrally located baffle with single hole.

REFERENCES

[1] M. L. Munjal 1987*Acoustics of Duct and Mufflers with application to exhaust and ventilation system.* New York: John Wiley and Sons.

[2] Z. Tao and A. F. Seybert2003*Society of Automotive Engineers, Inc.*,A Review of Current Techniques for Measuring Muffler Transmission Loss.

[3] Istvan L. Ver and Leo L. Beranek 2006 *Noise and Vibration Control Engineering principles and application*. New Jersey: second edition John Wiley & Sons, Inc.

[4] T.W. Wu,, C.Y.R. Cheng, Z. Tao, 2003 *Journal of Sound and Vibration*261 (2003) 1–15Boundary element analysis of packed silencers with protectivecloth and embedded thin surfaces

[5] Lawrence E. Kinsler, Austin R Frey, 1962 "*Fundamental of Acoustic"* John Wiley & Sons Inc, New York London

[6] A. K. M. Mohiuddin, AtaurRahman and Yazid Bin Gazali 2007 *Journal of mechanical and material engineering* Vol. 2 (No. 2. 118-124). Simulation and Experimental Investigation of Muffler Performance'

[7]www.wikibooks/EngineeringAcousticscarMufflersWikibooks,openbookforanorld.htm

[8]O. Vasile, Reactive Silencer Modeling with Boundary Element Method and Experimental Study, Proceedings of the 5th International Vilnius Conference, "Knowledge-Based Technologies and OR Methodologies for Strategic Decisions of Sustainable Development" (KORDS 2009), September 30-October 3, 2009, Vilnius, Lithuania, pp. 544-549, ISBN 978-9955-28- 482-6.

[9] C. Y. R. Cheng, T. W. Wu 1999 *Society of Automotive Engineers, Inc.* Exhaust muffler Design and Analysis Using A Boundary Element Method Based Computer Program

[10] S. N. Y. Gerges, R. Jordan, F. A. Thieme, J. L. Bento Coelho, J. P. Arenas 2005 *ABCM* Vol. XXVII, No. 2(132-140). Muffler Modeling by Transfer Matrix Method and Experimental Verification.

[11] Omid Z. Mehdizadeh and Marius Paraschivoiu 2005 *Applied Acoustics* 66 (2005) 902–918. A three-dimensional finite element approach for predicting the transmission loss in mufflers and silencers with no mean flow.

[12] A.D. Sahasrabudhe, M.L. Munjal and S. Anantha Ramu (1992), "Design of expansion chamber mufflers incorporating 3-D effects", Noise control engineering journal, Vol. 38(16), pp. 27-38.

[13] I. J. Lee and A. Selamet, N. T. Huff 2003, *Society of Automotive Engineers, Inc*, Acoustic Characteristics of Coupled Dissipativeand Reactive Silencers

[14] http://auto.howstuffworks.com/muffler3.htm

[15] Don D. davis, Jr., George M. Stokes, Dewey moore, and George L. Stevens, Jr. 1954 *NACA*, Report 1192. Theoretical and Experimental Investigation of Mufflers with Comments on Engine Exhaust Muffler Design.

[16] O. Vasile, Contributions on modelling of noise and vibration control, PhD thesis, 2009.

[17] Yoshihiro Isshiki, Yuzuru Shimamoto and Tomoyuki Wakisaka 1996 *Society of automotive Engineers, Inc*. 960637. Simulteneous prediction of pressure losses and acoustic characteristics in silencers by numerical simulation.

[18] MATLAB 7.10.0 2010 *user's guide*. The Mathworks Inc.

[19] International Standard 1998 ISO 10534-2;1998(E). Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-Function Method.

[20] http://www.silentor.com/filer/exhaust_silencer.pdf