A Review on Current Techniques for Acoustic Performance of An Automobile Exhaust Muffler

Rakesh B K
Department of Mechanical Engineering,
Jyothy Institute of Technology,
Bengaluru, Karnataka, India.

***Abstract*- This paper highlight basically on current techniques to achieve acoustic performance of an automobile exhaust muffler, the performance of a muffler is measured in terms of one of the parameter, insertion loss (IL), transmission loss (TL), level difference (LD) or noise reduction (NR). Consider transmission loss one of the parameter as a functional requirement to analyze an acoustic model from performance prospective. Exhaust noise must meet legislation targets, customer expectations and cost reduction with this initiative, initial analysis is made on the flow field of exhaust muffler of car by Computational Fluid Dynamics (CFD) software Fluent. Intake and Exhaust system noise makes a huge contribution to the interior and exterior noise, to be attenuated as transmission loss. The most simple and common approach to measure the transmission loss of a muffler is to determine the incident power by decomposition theory and the transmitted power by the plane wave approximation assuming an anechoic termination. But it is difficult to construct a fully anechoic termination, provided the pavement towards an alternative approaches like: Two load method, Two Source methods, Three point method, Four pole transfer matrix method and boundary element method which do not require an anechoic termination for validation of experimental test results.**

Keywords:- Transmission Loss (TL), Two Load Method, Exhaust Muffler, Three Point Method, Two Source Method, Anechoic Termination.

I. INTRODUCTION

Automotive Muffler plays important role in reducing the road noise caused by the automobile, lot of research is done in this area to design and analyze effectively the system. Accurate determination and control of noise from automobiles is of significant importance in automotive exhaust system design and development. To design a muffler of a vehicle, we should understand physical factors that affect the noise decrease in muffler. The noise from an exhaust system consists of three components: Pulsation noise, flow generated noise coming from the orifice of the muffler outlet and shell noise coming from the shell of the muffler, all these noise components caused due to influence of physical factors, such as geometric shape of a muffler, flow rate, the temperature gradient, and pressure wave resulted from engine combustion, can be limited by minimizing geometrical discontinuities (edges, sharp bends) and by using a stiffer or damped shell. That it is very difficult to select the most adequate muffler and muffler design. Objective of this review paper is to address on current techniques to construct acoustically perfect designed muffler to muffle noise of an automobile system. Research approaches on the acoustics characteristics of muffler include one-dimensional acoustic transfer matrix method, finite element method and boundary element theory, the method of transmission matrix based on 1-dimensional plane wave theory is the traditional way to study the acoustical performance. With the fast development of software and hardware of computer and the corresponding arithmetic improvement, finite element method (FEM) and boundary element method (BEM) have been becoming more and more popular for acoustics simulation of resistance muffler. FEM is applied to numerical calculate and analyze various types of muffler and BEM is particularly suited to solving the infinite domain problem for various types of muffler. “build & test” procedure which is time consuming and expensive, can nowadays be assisted by numerical simulation models which are able to predict the performance of several different muffling systems in a short time based on distinct assumptions. Respect to the above an alternative approaches like: Two load method, Two Source method, Three point method, Four pole transfer matrix method and Two microphone decomposition method are currently an essential techniques to improvise the acoustic performance characteristic of an automobile muffler.

II. TYPES OF MUFFLER

A. Two main types of mufflers, reactive and dissipative.

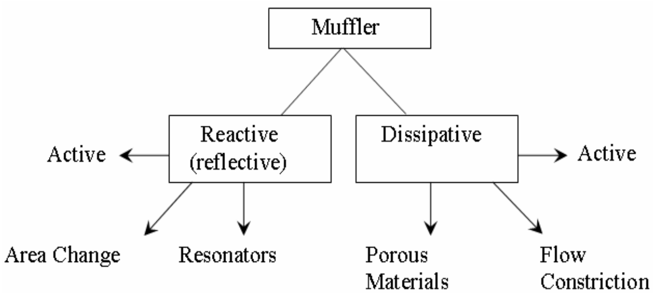


Fig1: Representing mufflers [1]

*Reactive***:**

Reactive mufflers are usually composed of several chambers of different volumes and shapes connected together with pipes, and tend to reflect the sound energy back to the source, they are essentially sound filters and are mostly useful when the noise source to be reduce contains pure tones at fixed frequencies or when there is a hot, dirty, high-speed gas flow. Reactive muffler for such purpose can be made quite inexpensively and require little maintenance [1].

Dissipative:

Dissipative mufflers are usually composed of ducts or chambers which are lined with acoustic absorbing materials that absorb the acoustic energy and turn it into heat. These types of mufflers are useful when the source produces noise in a broad frequency band and are particularly effective at high frequencies, but special precautions must be taken if the gas stream has a high speed and temperature and if it contains particles or is corrosive[1].

III. BASIC REQUIREMENT OF MUFFLER DESIGN

A. General requirements

- Quiet.
- Simple maintenance.
- Performance.
- Compact design.
- Light weight.

B. Specific requirements

- Reduce the sound emissions.
- Replaceable.
- Doesn't increase backpressure.
- Easy mounting.
- Within the budget.
- Easy manufacturing.

C. Muffler selection

- Determine the exhaust flow and acceptable exhaust system backpressure of engine.
- A free-flowing air intake and exhaust system in vehicle.
- Muffler must be built tough to handle high pressure exhaust gasses, absorb impact from road debris, and resist corrosion.
- Number of inlets, single or dual system.
- Diameter of pipe, Inlet and outlet.
- Size of the muffler.
- Material used, stainless steel muffler offers superior corrosion resistance, durability, and life span than the aluminized steel muffler.

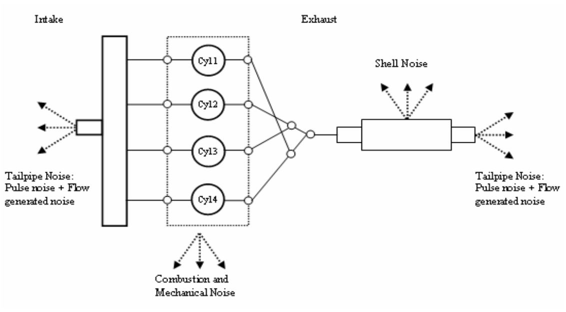


Fig2. Schematic of Engine Noise Sources [1]

IV. SIMULATION MODELS

A. The two types of simulation models currently in use

- *Linear Acoustic models*

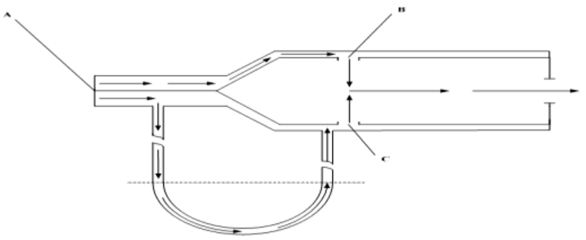
This is based on the hypothesis of small pressure perturbations within the ducts. Based on frequency domain techniques which for instance use the four-pole transfer matrix method to calculate the transmission loss of mufflers. This approach is very fast but the predicted results may be unreliable because the propagating pressure perturbations generally have finite amplitude in an exhaust system [1].

- *Non-linear gas dynamics models*

This describes the propagation of finite amplitude wave motion in the ducts. Based on time domain techniques, which simulate the full wave motion in the whole engine intake and exhaust system, to deal with finite amplitude wave propagation in high velocity unsteady flows it as to follow the gas flow from valves to open terminations. Excitation source can be modeled by means of appropriate boundary conditions for the flow in these simulations [1].

V. RESEARCH REVIEW

In 2005, A.K.M.Mohumuddin presents experimental study of noise and back pressure for silencer design characteristics. The main objective of this study was to find the relationship between the back pressure and the noise level. He concludes that the relationship between the noise and the back pressure is inversely proportional [1]. In 2010, Chndreshkumar Bhat et al. have study on design and analysis of expansion chamber mufflers. In that study, they used model analysis followed by acoustic analysis using finite element analysis technique for three different configurations of mufflers under different fixing conditions. He was found that three chamber muffler provides higher attenuation of sound pressure compare to one and two chamber mufflers. And fixing the muffler at the centre enhances sound pressure attenuation. He concludes that the transmission loss is minimum at resonance. The transmission loss increases with the increase in number of chambers and loss is uniform [2]. In 2010, Wang jie et al. have study on the model analysis of an automobile exhaust muffler based on PRO/E and ANSYS in order to improve design efficiency. The solid model is created by PRO/E and model analysis is created out by ANSYS to study the vibration of the muffler, so as to distinguish working frequency from natural frequency and avoid resonating. Data exchange between PRO/E and ANSYS using IGES (Elementary graphics exchange specification) format for data exchange specification. Muffler natural frequencies modal shapes have been calculated by the FEM analysis software named ANSYS. So the muffler vibration can be intuitive analyzed. The natural frequencies and mode shape are considered during the design of the muffler, so avoid the resonance occurred in exhaust system [3].In 2010, Mehmet Avcu et al. introduce diesel engine exhaust system design with help of the three-dimensional model of the system has been constructed by using “ANSYS Workbench”, the mathematical models via Finite Element Method (FEM) have been done via “ANSYS ICEM CFD” and, the Computational Fluid Dynamics (CFD) analyses covering back pressure and thermal analyses have been performed by using “ANSYS CFX 12” program. He Conclude, The dimensions and internal structure of the dry and wet-type silencers which are the main components of the exhaust system and the physical properties of the insulation material have been determined based on acoustic, back pressure and thermal analyses and, the layout of the diesel engine in the engine room. From the results of the back pressure analyses, it is seen that the total back pressure in the whole exhaust system is within the limits of the given diesel engine criteria and, the board outlet temperature of the exhaust system is substantially low[4].In 2011, Ying Li Shao et al. have a study on a Exhaust Muffler Using a Mixture of Counter phase Counteract and Split-gas Rushing. In order to solve the problems of traditional exhaust silencers with poor characteristics of noise reduction in low-frequency range and high exhaust resistance, a new theory of exhaust silencer of diesel engine based on counter-phase counteract and split-gas rushing has been proposed. In single-cylinder diesel engine CG25 as the experimental engine. He measured the exhaust noise and its spectra. By comparing the results of the new types of mufflers to those without a muffler and those with the original muffler of the engine.He conducted on this noise experiment that the CG25 single cylinder diesel engine shows new muffler‟s good insertion loss characteristic in the wide range of engine speed comparable to the original passive muffler especially in the range of 500 Hz. The original muffler can only reduce the high-frequency noise components, it cannot reduce, even strengthen the noise of frequency below 500 Hz, proved conventional muffler with poor capacity of lowering the low-frequency noise again. The new exhaust mufflers were obviously effective in controlling the low-frequency exhaust noise, which proved correctness of the new theory not only proved that the new mufflers have very good performance for low-frequency noise reduction, but also proved that using split-gas rushing can lower the air flow speed thus lowering the air regeneration noise.fig 2 shows the new design of muffler [5].



In 2011, Shi Wu et al. have study on Structural Design and Testing Study of Truck Muffler. He introduces the performance evaluation method of automobile's exhaust muffler and it‟s the size parameter to the noise elimination effect influence. It presents a two chambers impedance compound exhaust muffler designment's method based on a boundary element method, which focuses on the truck's diesel engine. Test shows that the truck exhaust muffler has a good effect with insertion loss of 22.7dB, and by the boundary element method, calculates transmission loss under the static condition. By the experiment he conclude that By laying cotton blankets absorbing sound on the inner surface of the truck muffler, not only can we solve the exhaust noise of the mid and high frequency band, and isolate the exhaust heat out of the radiation. By blocking imports of gas to prevent gas through, the muffler avoids the high frequency noise transmission to meet the technical requirements [6].In 2011, Jun Chan investigates CFD Numerical Simulation of Exhaust Muffler based on the physical numerical modelling of the flow field of the muffler in this paper, the author simulated the field by numerical method with Fluent and analyzed the effect which the internal flow field has on the performance of the muffler. The author simulated the field by numerical method with Fluent and analyzed the effect which the internal flow field has on the performance of the muffler[7].In 2012, M RAJASHKUMAR REEDDY explain design and optimization of exhaust muffler in automobiles by study of Muffler dimensions are measured through the Benchmarking, to create CAD models. The CAD models are created in CATIA V5 R19, later these CAD models of muffler are exported to HYPER MESH for pre-processing work. Free analysis is carried out on this muffler by FEA Method using NASTRAN Software. In order to determine the resonance frequencies, were then compiled to determine which peaks were the most significant for the system. From the data, side baffles were selected as weak parts of the muffler. In order to minimize the effects of these resonance frequencies, the suggested design improvement is to add thickness and also add damping to the system [8].In 2012, Hua HUANGE et al. have study Multi-objectives Optimization on Exhaust Muffler Based on DoE. He builds comprehensive evaluation system and DoE development flows are built. RBF mathematical models of evaluated objectives are established to look for Pareto optimal solutions. he define design parameters(diameter of inlet and outlet pipe, position of Clapboard 1 and Clapboard 2, open hole rate of Clapboard 1 and Clapboard 2, length of inlet pipe in the second cavity, and length of middle pipe in the third cavity). Define optimized objectives, Building comprehensive evaluation system for Muffler, he use 2k factor analysis is the first step of DoE optimization, Build mathematical model. This paper builds muffler DoE development flow, and does multi-objectives research. Based on DoE way, it builds RBF mathematical model of each objective, and gets 300 Pareto optimal solutions (based on equable change of weight of optimized objectives) from RBF model by using NSEA+ arithmetic[9].In 2013, Ehsan Sabah M. AL-Ameen et al. do Experimental Test for Noise Attenuation in Gasoline Engine with Different Types of Mufflers. Compares between three different types of an exhaust muffler for noise attenuation of single cylinder four stroke air-cooled gasoline engine. A set of conclusions achieved about the effect of the mufflers chamber's expansion ratio, chambers length, and wall thickness. Sound attenuation of 12.5, 15 and 16 dB A is achieved with, Multi-chamber Reactive

ISSN: 2278-0181
ETMET - 2016 Conference Proceedings

Muffler, Concentric-tube Resonator Muffler and Combined Reactive and Dissipative Muffler[10]. In 2013, Takashi Yasuda Studies on an automobile muffler with the acoustic characteristic of low-pass filter and Helmholtz resonator. Based on the typical structure, a muffler with an interconnecting hole on the tail pipe was proposed to improve its acoustic performance. Acoustic performances of the proposed muffler were studied experimentally and theoretically in frequency and time domain. Results showed that the specimen muffler had attenuation performances of low-pass filter and Helmholtz resonator when an interconnecting hole was designed on the tailpipe [11].

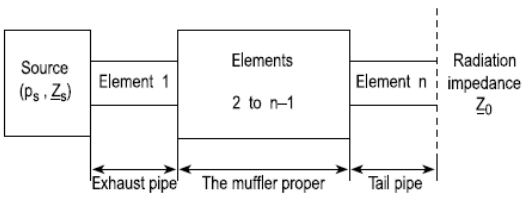
VI. MUFFLER PERFORMANCE PARAMETERS

A. The performance of a muffler is measured in terms of one of the following parameters

- Insertion loss (IL),
- Transmission loss (TL),
- Level difference (LD) or noise reduction (NR).

Insertion loss (IL):

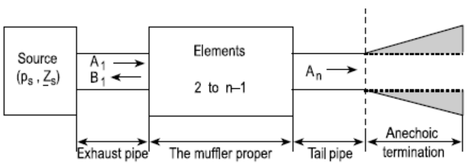
Defined as the difference between the acoustic power radiated without any muffler and that with the muffler (inserted, as it were between the source and the radiation load impedance), as shown in the figure.



$$IL = 20\log\left[\left(\frac{R_{e1}}{R_{en}}\right)^{1/2}\left|\frac{Z_{rn}T_{11} + T_{12} + Z_{rn}Z_sT_{21} + Z_sT_{22}}{Z_{r1} + Z_s}\right|\right]$$

Transmission loss (TL):

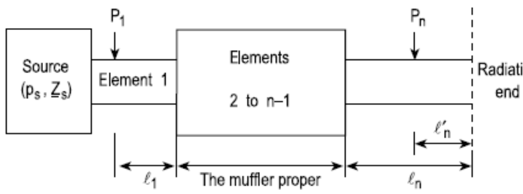
Independent of the source and presumes (or requires) an anechoic termination at the downstream end. It is defined as the difference between the power incident on the muffler proper and that transmitted downstream into the anechoic termination, as shown in the figure.



$$TL = 20\log\left[\left(\frac{\underline{Z}_n}{\underline{Z}_1}\right)^{1/2}\frac{(1+M_1)}{2(1+M_n)}\left|T_{11} + T_{12}/\underline{Z}_n + T_{21}\underline{Z}_1 + T_{22}\underline{Z}_1/\underline{Z}_n\right|\right],$$

The level difference (LD) (or noise reduction, NR):

The difference in sound pressure levels at two arbitrarily selected points in the exhaust pipe and tailpipe, as shown in the figure.



$$LD = 20\log\left|\frac{T_{11} + T_{12}/Z_{rn}}{\cos(k_0\ell'_n) + j\underline{Z}_n\sin(k_0\ell'_n)/Z_{rn}}\right|$$

VII. CURRENT TECHNIQUES

A. Decomposition Method or Three Point Method
B. Two Source Method.
C. Two Load Method.

A. Decomposition method

The muffler TL is the acoustical power level difference between the incident and transmitted waves assuming an anechoic termination.

$$TL = 20\log_{10}\left(\frac{W_i}{W_t}\right) \tag{1}$$

W_i is the incident sound power
W_t is the transmitted sound power.

Generally, the transmitted sound power can be easily obtained by simply measuring the sound pressure at the outlet. The corresponding sound power can be related to the sound pressure if a plane wave with no reflection is assumed. However, the incident sound power is more difficult to measure due to the sound reflection from the muffler. As shown in Figure3, for one-dimensional sound traveling along a duct, a standing wave develops when a change in the impedance is encountered at the muffler inlet. The sound pressure can be decomposed into its incident and reflected spectra, SAA and SBB, respectively. One way to decompose the wave is to use the two-microphone method and to separate the waves using decomposition Theory

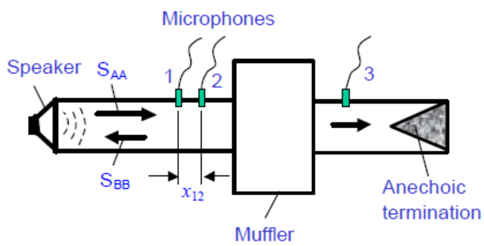


Fig3: Setup of decomposition theory

By decomposition theory, the auto spectrum of the incident wave SAA is

$$S_{AA} = \frac{S_{11} + S_{22} - 2C_{12}\cos kx_{12} + 2Q_{12}\sin kx_{12}}{4\sin^2 kx_{12}} \tag{2}$$

Where S11 and S22 are the auto spectra of the total acoustic pressure at points 1 and 2, respectively; C12 and

Q12 are the real and imaginary parts of cross spectrum between points 1 and 2; k is the wave number; and X12 is the distance between the two microphones. The rms amplitude of the incident wave sound pressure P_i can be founded from,

$$p_i = \sqrt{S_{AA}} \qquad (3)$$

It follows that the sound power for each wave can be expressed in terms of the incident (pi) and transmitted (pt) rms pressure amplitudes as,

$$W_i = \frac{p_i^2}{\rho c} S_i \qquad (4)$$

$$W_t = \frac{p_t^2}{\rho c} S_o \qquad (5)$$

Respectively. In Equations (4) and (5), ρ ıs the fluid density, c is the speed of sound, and S_i and S_o are the muffler inlet and outlet tube areas, respectively. Inserting Equations (4) and (5) into Equation (1), the TL can be expressed as

$$TL = 20\log_{10}\frac{p_i}{p_t} + 10\log_{10}\frac{S_i}{S_o} \qquad (6)$$

A common error is to attempt to apply decomposition method to downstream of the muffler using a pair of microphones if the termination is not anechoic. This will not work as it is not the same as the incident" wave sound pressure downstream. The TL for the expansion chamber shown in Figure 2 was measured by the decomposition method. An anechoic termination whose absorption coefficient is about 0.95 over 100-3000 Hz frequency range was used in the measurement. The TL results are compared to numerical results from the BEM (also shown in Figure 4). It is apparent that the measured results deviate from the BEM results over the whole frequency range. This is likely due to the termination not being perfectly anechoic [3].

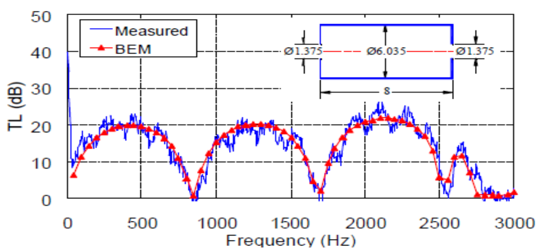


Fig4: Decomposition method vs. BEM
(Muffler dimensions in inches)

B. Two Source Method

The two-source method is based on the transfer matrix approach. An acoustical element can be modeled by its Four-pole parameters

$$\begin{bmatrix} p_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_2 \\ v_2 \end{bmatrix}$$

where *p*1 and *p*2 are sound pressures at the inlet and outlet, and *v*1 and *v*2 are the particle velocities at the inlet and the outlet, respectively, *T*11, *T*12, *T*21, and *T*22 are the four-pole parameters. The inlet and outlet points are chosen to be inside the inlet and outlet pipes close to the pipe ends.

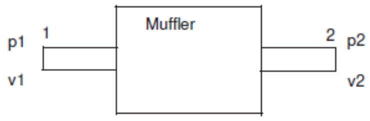


Fig 5 Four-poles.

In this method two different configurations of muffler are solved using Coustyx as tool to obtain *p*1, *p*2, *v*1, and *v*2. Configuration *a* or Case1 has the source or excitation at the inlet and a rigid outlet.

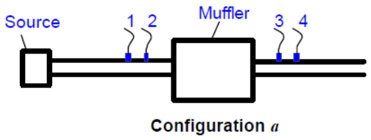


Fig 6 Setup of two-source method

$$\begin{bmatrix} p_{1a} \\ v_{1a} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_{2a} \\ v_{2a} \end{bmatrix}$$

For Configuration *b* or Case2 the source is switched to the side of the outlet and the inlet is made rigid. Therefore, for Configuration *b* or Case2 the transfer relation is rewritten as

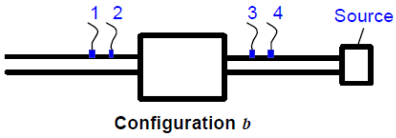


Fig 7 Setup of two-source method

$$\begin{bmatrix} p_{2b} \\ -v_{2b} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}^{-1} \begin{bmatrix} p_{1b} \\ -v_{1b} \end{bmatrix}$$

OR

$$\begin{bmatrix} p_{2b} \\ v_{2b} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} T_{22} & T_{21} \\ T_{12} & T_{11} \end{bmatrix} \begin{bmatrix} p_{1b} \\ v_{1b} \end{bmatrix}$$

Where Δ= *T*11*T*22 ¡ *T*12*T*21, and the particle velocities *v*1*b* and *v*2*b* are in the direction of the flow for Configuration *b*, that is, from the outlet to the inlet.

The four-pole parameters are then solved in terms of pressure and velocities as follows

$$T_{11} = \frac{(p_{1a}v_{2b} + p_{1b}v_{2a})}{(p_{2a}v_{2b} + p_{2b}v_{2a})}$$

$$T_{12} = \frac{(p_{1a}p_{2b} - p_{1b}p_{2a})}{(p_{2a}v_{2b} + p_{2b}v_{2a})}$$

$$T_{21} = \frac{(v_{1a}v_{2b} - v_{1b}v_{2a})}{(p_{2a}v_{2b} + p_{2b}v_{2a})}$$

$$T_{22} = \frac{(p_{2a}v_{1b} + v_{1a}p_{2b})}{(p_{2a}v_{2b} + p_{2b}v_{2a})}$$

The transmission loss for a mu²er, in terms of four-pole parameters and inlet (*Si*) and outlet (*So*) tube areas, is given by

$$TL = 20\log_{10}\left[\frac{1}{2}\left|T_{11} + \frac{T_{12}}{Z_o} + T_{21}Z_o + T_{22}\right|\right] + 10\log_{10}\left(\frac{S_i}{S_o}\right)$$

The TL comparison is shown in Figure 8 for the expansion chamber used previously in Figure 5. The two-source method agreed especially well with the BEM results. The termination was the straight tube with absorbing material [3].

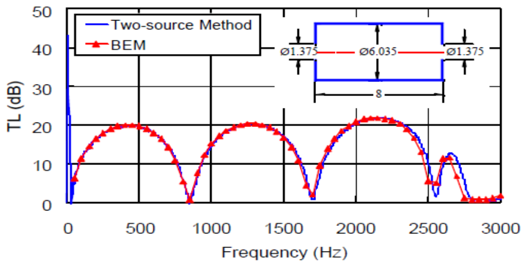


Fig 8 Two-source method vs. BEM (Muffler dimensions in inches)

C. Two Load Method

We can clearly observe that there are four unknowns and has only two equations *A23, B23, C23* and *D23*, but there are only two equations. Instead of moving the sound source to the other end to get two additional equations, the same result can be obtained by changing the end condition, as shown in Figure 9

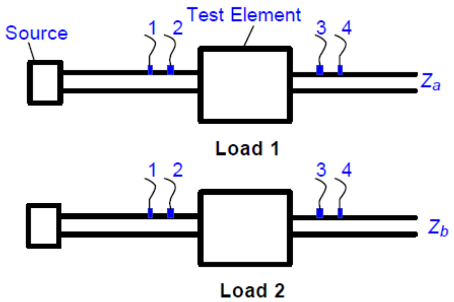


Fig 9 Setup of two-load method

Changing the end condition effectively changes the impedance at the termination from *Za* to *Zb*. The four-pole parameters of element 2-3 can be obtained

In the two-load method, it is obvious that if two loads are very similar, the result will be unstable. Generally, two loads can be two different length tubes, a single tube with and without absorbing material, or even two different mufflers. In this research, two loads were achieved by a tube with and without absorbing material.

.

Though the TL was measured accurately by the two-load method, the four-pole parameters are not as clean as those measured using the two-source method. This may be due to the two loads not being sufficiently different in 500-1500 Hz range [3].

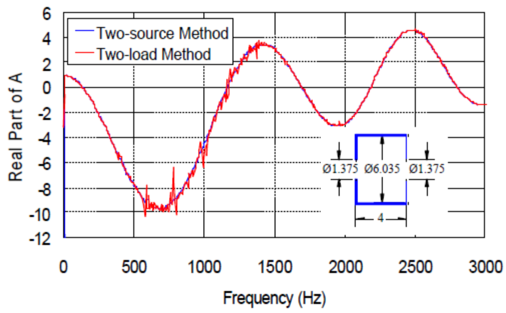


Fig 10 Real part of the four pole parameter (Muffler dimensions in inches)

VIII. CONCLUSION

The different methods used for measuring the transmission Loss are discussed in this paper. A review projects a clear understanding of current techniques and their applicability towards the acoustic performance approach and limitation of certain conventional techniques.

The major drawback of the decomposition method is that an anechoic termination is required for measuring transmission loss (TL). In practice, anechoic termination could be constructed using a long exhaust tube are high absorbing materials, a “fully” anechoic termination is difficult to build, particularly one that is effective at low frequencies. Whereas other techniques measure the transmission loss accurately without the perfect anechoic termination like, Two source and Two load methods mainly contributed to measure and calculate effectively transmission loss. Two load method measures transmission loss (TL) accurately by four-microphone approach, which determined four-pole parameters, are not still as perfect as those measured by using the two-source method. The reason was unstable when the two loads were not “sufficiently” different over the entire frequency range of the order 500-1500 Hz as depicted in the fig 10. Henceforth the two source method which employed four pole transfer matrix method, provided a much matured result and is a better choice for determining acoustic performance of an automobile muffler among other techniques.

REFERENCE

[1] Sathish Kumar Linear Acoustic Modelling And Testing of Exhaust Mufflers Royal Institute of Technology.

[2] Mr. Jigar H. Chaudhri et al Int. Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, Vol. 4, Issue 1(Version2), January 2014, pp.220-223.

[3] Z. Tao and A.F. Seybert. A review of current techniques for measuring muffler transmission loss.SAE International, 2003.

[4] http://www.ansol.comMuffler Transmission Loss {Simple Expansion Chamber}.

[5] M.L.Munjal.K : Muffler Acoustics

[6] Munjal, M.L.: Velocity ratio cum transfer matrix method for the evaluation of a muffler with mean flow J. Sound Vibr. 39, 105–119 (1975).

[7] M. L. Munjal, *Acoustics of Ducts and Mufflers*, page 21, 55-59, 201-205. John Wiley & Sons, Inc. (1987).

[8] Munjal, M.L. and Doige A.G., “Theory of a Two Source-location Method for Direct Experimental Evaluation of the Four-pole Parameters of an Aeroacoustic Element,” Journal of Sound and Vibration,141(2), 323-333 (1990).

[9] C.A.Brebbia and R. D. Ciskowski. *Boundary Element Methods in Acoustics*. Computational Mechanics Publications, 1991.

[10] T.W. Wu and G. C. Wan. Muffler performance studies using a direct mixed-body boundary element method and a three-point method for evaluating transmission loss. *ASME Transaction, Journal of Vibration and Acoustics*, 118:479{484, 1996.

[11] E. B. Magrab. *Environmental Noise Control*. John Wiley & Sons, New York, 1975

[12] COMSOL 3.4, *Acoustic Module Model Library*, 74-89, 154-170. COMSOL AB (2007)

[13] Seybert, A.F. and Ross, D.F., "Experimental Determination of Acoustic Properties Using a Two microphone Random Excitation Technique," J. Acoust. Soc. Am., 61, 1362-1370 (1977).

[14] 2005, A.K.M. Mohumuddin, Mohd Rashidin Ideres and Shukari Mohad Hashim, „"Experimental study of noise and back pressure for silencer design characteristics"", Journal of Applied Science5(7):1292-1298,2005 ISSN 1812-5654.

[15] 2010, Chandrashekhar Bhat, S S Sharma, Jagannath K, N S Mohan, Sathisha S G, „„ Design and Analysis of a Expansion Chamber Mufflers"". World Journal Of Engineering, volume 7, supplement 3, 2010, ISSN: 1708-5284.

[16] 2010, Wang jie and Dong-peng Vue. The Modal Analysis of Automotive Exhaust Muffler Based on PROlE and ANSYS. 20IO 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE). 2010 IEEE

[17] 2010, Mehmet Avcu, Şadi Kopuz and Mehmet Teke." DIESEL ENGINE EXHAUST SYSTEM DESIGN "" Journal of Naval Science and Engineering 2010, Vol. 6, No.1, pp. 39-58.

[18] 2011, Ying Li Shao. A Study on Exhaust Muffler Using a Mixture of Counter phase Counteract and Split-gas Rushing. © 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of [CEIS

[19] 2012, 1M RAJASEKHAR REDDY & 2 K .MADHAVA REDDY. DESIGN AND OPTIMIZATION OF EXHAUST MUFFLER IN AUTOMOBILES International Journal of Automobile Engineering Research and Development (IJAuERD) ISSN 2277-4785 Vol.2, Issue 2 Sep 2012 11-21.

[20] 2012, Hua HUANGEJimin NI, Qianying DU, Nan XIE, Multi-objectives Optimization on Exhaust Muffler Based on DoE. 2012 Fourth International Conference on Computational and Information Sciences.©2012 IEEE DOI 10.1109/ICCIS.2012.189.

[21] 2013, Ehsan Sabah M. AL-Ameen. Experimental Test for Noise Attenuation in Gasoline Engine with Different Types of Mufflers Journal of Engineering and Development, Vol. 16, No.4, Dec. 2012 ISSN 1813- 7822

[22] 2013, Takashi Yasud , Chaoqun Wu, Noritoshi Nakagawa , Kazuteru Nagamura . Studies on an automobile muffler with the acoustic characteristic of low-pass filter and Helmholtz resonator. Applied Acoustics 74 (2013) 49–57. 2012 Elsevier Ltd.http://dx.doi.org/10.1016/j.apacoust.2012.06.007