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A REVIEW ON CURRENT TECHNIQUES FOR ACOUSTIC PERFORMANCE OF AN AUTOMOBILE EXHAUST MUFFLER

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ABSTRACT: Currently, the primary focus of this research is on methods for improving the sound performance of automotive exhaust mufflers. Mufflers' effectiveness is measured in several ways, including noise reduction (NR), insertion loss (IL), and transmission loss (TL). When doing a performance analysis of an acoustic model, it is critical to consider transmission loss as a functional requirement. Initially, computational fluid dynamics (CFD) software is used to examine the flow field of an exhaust filter for a car. The objectives are to save costs, ensure that the project respects the standards, and satisfy customers regarding the pollution from the exhaust. The noise from the intake and exhaust systems has a significant impact on both internal and external noise levels. Transmission loss significantly lessens the noise. The simplest and most popular method for determining a muffler's transmission loss is to use the plane wave approximation and decomposition theory to calculate the transmitted and incident power given an anechoic termination. However, it is difficult to achieve a complete anechoic termination. This is especially true given the increasing number of validation procedures for experimental test results that do not require an anechoic termination. These include the two load method, the two source method, the three point method, the four-pole transfer matrix method, and the boundary element method.

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

1.INTRODUCTION

Exhaust systems are required to reduce the noise that cars emit on the road. A great deal of scholarly study has gone into developing and assessing these systems. It is critical to properly evaluate and manage vehicle noise while designing and developing exhaust systems for automobiles. A person who wishes to create a car's muffler should understand the physical components that impact how well the muffler blocks noise. There are three factors that can make an exhaust system noisy: You can reduce the effects of these noise types—pulsation noise, flow-generated noise from the muffler output orifice, and shell noise from the muffler's shell—by strengthening or dampening the shell and changing factors such as the muffler's shape, flow rate, temperature gradient, and engine combustion pressure wave. because it is difficult to select the appropriate silencer and muffler style.The purpose of this review article is to look at new approaches to build mufflers that effectively reduce noise from automotive systems. The most frequent approaches to studying muffler sound features are the one-dimensional acoustic transfer matrix method, the finite element method, and boundary element theory. The transmission matrix approach is based on one-dimensional plane waves. Finite element methods (FEM) and boundary element approaches (BEM) are increasingly employed to mimic the sound of resistance mufflers. This is due to the increasing sophistication of computer systems, as well as the improvement of software and hardware. FEM is used to study and numerically calculate many types of mufflers, whereas BEM seeks the optimal solution to the infinite domain problem that these varied types of mufflers contribute to. Today's "build and test" processes are time consuming and expensive. Numerical simulation models can simplify these operations by quickly and precisely estimating how different muffling devices will perform under various assumptions. A variety of strategies, including the two load, two source, three point, four pole transfer matrix, and two microphone decomposition methods, can now be used to change the sound of automotive mufflers

2.TYPES OF MUFFLERS

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

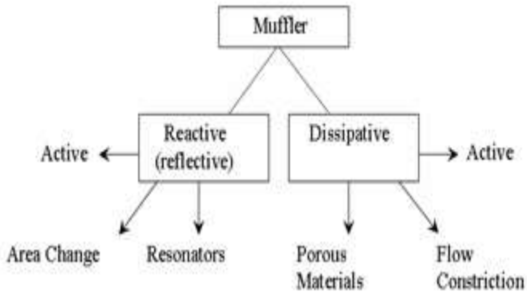


Fig1:Representing mufflers

Reactive:

Reactive mufflers are simply sound filters that work best when the noise source delivers clear tones at specified frequencies or when the gas flow is turbulent, filthy, and hot. They are often made up of several chambers that are connected by pipes and vary in size and design. Reactive mufflers almost always return sound energy to its source. Reactive mufflers with little to no maintenance can be manufactured at a low cost for this application .

Dissipative:

The majority of dissipative mufflers are made of cylinders or tubes lined with materials that absorb sound energy and convert it to heat. A considerable proportion of noise comes from a single source, and these mufflers work well at high decibel levels. When particles are mixed with an acidic or extremely hot gas stream, further vigilance is required.

BASICREQUIREMENTOFMUFFLERDESIGN

A. **General requirements**

It is compact, lightweight, silent, effective, and simple to maintain.

B. **Specific requirements**

- Reduce levels of noise pollution.
- Progressing positively. does not exacerbate the back discomfort.
- Simple to affix.
- within the specified budget.
- Simple production processes.

C. **Muffler selection**

- Determine the exhaust flow of the engine and the utmost allowable backpressure in the exhaust system.
- automobile in which air enters and exits via open ducts.
- In order to withstand road debris, corrosion, and high-pressure exhaust gases, mufflers must be constructed

from durable materials.

- The quantity of inlets, which may be one or two.
- The breadth of the pipe at its inlet and outlet.
- The exhaust's girth and length.
- In terms of longevity, corrosion resistance, and durability, stainless steel mufflers surpass their aluminized steel counter part.

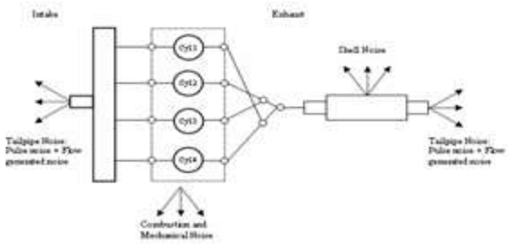


Fig2.Schematic of Engine Noise Sources

3.SIMULATION MODELS

A.The two types of simulation models currently

Linear Acoustic models

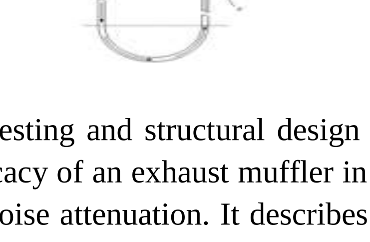
This is based on the assumption that conduits undergo minute pressure variations. The computation of transmission loss for mufflers is possible through the utilization of frequency domain methodologies, such as the four-pole transfer matrix style. While this approach demonstrates a rapid execution rate, the expected results may be unreliable on account of the finite amplitude of pressure perturbations that propagate within an exhaust system.

Non-linear gas dynamics models

This clarifies the process by which wave motion with a finite amplitude traverses the conduits. To account for finite amplitude wave propagation in turbulent flows at high velocities and simulate the complete wave motion in the engine intake and exhaust system, time domain techniques are used to model the gas flow from the open terminations of the valves. The excitation source can be depicted in these simulations by flow-appropriate boundary conditions .

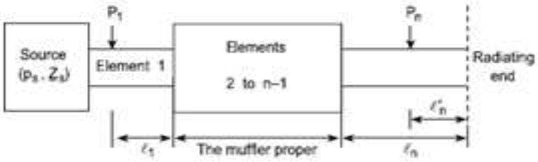
RESEARCH REVIEW

In 2005, an experimental investigation conducted by A.K.M. Mohumuddin examined the impact of noise and back pressure on the design characteristics of silencers.The principal aim of this research was to establish a correlation between the level of noise and back pressure. The author arrives at the deduction that a negative proportionality exists between backpressure and noise [1].In 2010, a study was conducted by Chndreshkumar Bhat et al. regarding the analysis and design of expansion chamber mufflers. The study employed finite element analysis for acoustic analysis subsequent to model analysis. The investigation scrutinized three unique muffler configurations while subjected to different fixation conditions. It was discovered that mufflers with three chambers are more effective at reducing sound pressure than those with one or two chambers. By additionally affixing the muffler in the center, the reduction of sound pressure is enhanced. He concludes that transmission loss is negligible at resonance. As the quantity of chambers increases, the uniformity of transmission loss also escalates [2]. In 2010, Wang Jie et al. conducted research utilizing PRO/E and ANSYS to analyze the model of an automobile exhaust muffler with the objective of enhancing design efficiency. A solid model is generated by conducting an analysis of the muffler's vibration using ANSYS and PRO/E. This model is critical for distinguishing between working frequency and natural frequency, as well as for mitigating resonation. The elementary graphics exchange specification (IGES) format serves as the data exchange specification between PRO/E and ANSYS. The modal morphologies of the natural frequencies of mufflers were calculated utilizing the finite element software ANSYS. To intuitively analyze the vibration of the muffler. To mitigate resonance in the exhaust system, consideration is given to the mode shape and inherent frequencies during the design of the muffler [3].In 2010, Mehmet Avcu et al. introduced the design of an exhaust system for diesel engines. The researchers employed the "ANSYS Workbench" software to generate a three-dimensional model of the system, the "ANSYS ICEM CFD" software to implement mathematical models using the Finite Element Method (FEM), and the "ANSYS CFX 12" software to perform thermal and back pressure analyses as part of computational fluid dynamics (CFD). Following acoustic, back pressure, and thermal analyses, as well as consideration of the diesel engine's configuration in the engine room, the author concluded, the physical properties of the insulation material, dimensions and internal structure of the dry and wet-type silencers (the primary components of the exhaust system), and back pressure and thermal analyses have been determined. The results obtained from the back pressure analyses suggest that the exhaust system's overall back pressure meets the requirements specified for the diesel engine. Furthermore, there is a substantial reduction in the board discharge temperature of the exhaust system [4].In 2011, Ying Li Shao et al. conducted research pertaining to an exhaust muffler that employed a hybrid configuration consisting of split-gas rushing and counter-phase rushing. In order to mitigate the limitations of traditional exhaust silencers, such as insufficient suppression of low-frequency noise and elevated resistance to exhaust, an innovative concept has been proposed concerning diesel engine exhaust silencers that utilize split-gas rushing and counter-phase counteract. Single-cylinder diesel motor The powerplant being tested is CG25.Exhaust noise and spectrum measurements were performed by him. Through the implementation of a comparative investigation of the engine's outputs while and without the initial muffler are considered.Based on the findings of this noise experiment, it can be concluded that the CG25 single-cylinder diesel engine, when equipped with the new muffler, demonstrates improved insertion loss characteristics at a wide range of engine velocities compared to the initial passive muffler. This improvement is especially pronounced in the frequency range of 500 Hz. The capability of the initial muffler is restricted to the attenuation of high-frequency noise components. It lacks the ability to reduce or even amplify noise frequencies below 500 Hz. As a consequence, traditional mufflers are once again ineffective at attenuating low-frequency noise. The efficacy of the novel exhaust mufflers in controlling low-frequency exhaust noise clearly substantiated the novel theory. This demonstrated not only the exceptional performance of the new mufflers in reducing low-frequency exhaust noise, but also the ability of split-gas hurrying to decrease air flow velocity, consequently resulting in a reduction in air regeneration noise.Fig. 2 depicts the design of the modified muffler



Shi Wu et al. investigated the testing and structural design of car mufflers in 2011. The author describes a method for determining the efficacy of an exhaust muffler in a motor vehicle, with a focus on the relationship between muffler diameter and noise attenuation. It describes a boundary element method-based two-chamber impedance compound exhaust muffler design method, focusing on the vehicle's diesel engine.The vehicle exhaust muffler performs quite well, as indicated by an insertion loss of 22.7 dB as measured by the tests. When the surrounding environment is constant, the transmission loss is estimated using the boundary element approach. According to the findings of his studies, installing sound-absorbing blankets inside the vehicle muffler can insulate exhaust heat from radiation while also eliminating mid- and high-frequency exhaust noise. The muffler meets technical standards by limiting gas passage and preventing high-frequency noise transmission [6].In 2011, Jun Chan looked at using CFD to numerically simulate an exhaust muffler. The author's physical numerical modeling of the muffler's flow field served as the foundation for this inquiry. Chan explored the effect of the interior flow field on muffler efficacy by numerically simulating it with Fluent. Using Fluent, the author ran a numerical simulation of the internal flow field to determine its impact on the muffler's efficacy [7].MRAJASHKUMARREEDDY (2012) investigated the generation of CAD models using benchmarked muffler dimensions, as well as the design and optimization of automotive exhaust mufflers. CATIA V5 R19 is used to create resonator CAD models, which are then exported to HYPERMESH for initial processing. We do a no-cost analysis of this muffler using the FEA Method and NASTRAN Software. The resonance frequencies were then determined by compiling the system's most noticeable peaks. The research showed that the exhaust's side baffles were weak points. To reduce the effects of these resonance frequencies, increase the system's thickness and damping [8].According to the DoE, Hua Huange et al. studied multi-objective optimization for exhaust mufflers in 2012. He sets up DoE development methods and builds a comprehensive evaluation system. RBF mathematical models are used to find Pareto optimal solutions for the objectives under consideration. He specifies the length of the middle pipe in the third cavity, the size of the outlet and inlet pipelines, the location of Clapboards 1 and 2, and Clapboards 1 and 2's open hole rate. Setting appropriate objectives. After creating a complete evaluation methodology for Muffler, he began DoE optimization by doing 2,000 factor studies. Construction of a mathematical model. This article covers the findings of research with several aims and outlines a development pipeline for a muffler DoE. The DoE approach is used to create an RBF mathematical model for each aim. Using NSEA+ arithmetic, the 300 Pareto optimal solutions (defined by the equable change in weight of optimized objectives) are recovered from the RBF model [9]. In 2013, Ehsan Sabah M. AL-Ameen et al. conducted an experimental study to determine the effectiveness of various types of mufflers in reducing pollution in gasoline engines. This article examines and analyzes three different types of exhaust mufflers intended to lower the noise output of a four-stroke, air-cooled, single-cylinder gasoline engine. A collection of findings about the effects of the resonator chamber's length, expansion ratio, and wall thickness. A variety of compartments provide sound attenuation of 15, 16, and 12.5 dBA.Muffler for the reactive concentration tubes.Resonator, dissipative, and reactive mufflers were integrated [10]. 2013 was noted. Takashi Yasuda The Helmholtz resonator and acoustic features of a low-pass filter were used to investigate the characteristics of an automotive muffler. To increase the acoustic performance of the system, an interconnecting opening on the exhaust pipe was proposed for the muffler, which was an upgrade over the typical design. The suggested suppressor's experimental and theoretical acoustic performance was assessed in both the frequency and temporal domains. The results showed that adding an interconnecting aperture to the exhaust led the specimen muffler to attenuate to the same level as a low-pass filter and Helmholtz resonator [11].

The graphic depicts the discrepancy in sound pressure levels between two randomly selected points within the exhaust pipe and tailpipe.



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

4.MUFFLER PERFORMANCE PARAMETERS

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

Insertion loss (IL), level differential (LD), noise reduction (NR), and level differential (LD). IL: Loss of Insertion Defined as the fluctuation in acoustic intensity

CURRENT TECHNIQUES

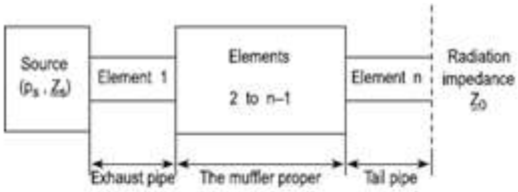
- Decomposition Method: Two-Source Approach and Three-Point Approach.
- The method of two loads.

A. **Decomposition method**

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

The object was subjected to radiation both with and without a muffler, which functioned as an intermediary between the radiation source and the radiation. Load impedance), as illustrated in the figure.

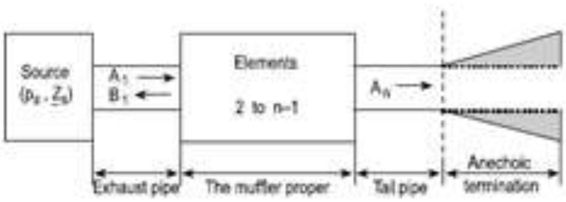
$$TL=20\log_{10}\left(\frac{W_i}{W_t}\right) \qquad (1)$$



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

Transmission loss(TL):

It is source-independent and an anechoic termination downstream is assumed (or required). It is the difference between the power incident on the muffler and the power transported downstream to the anechoic termination, as depicted in the image.



W_i is the incident sound power

W_t is the transmittedsound power.

When the sound pressure at the egress is measured, the transmitted sound power can typically be determined. Assuming a plane wave with no reflection, it is possible to establish a relationship between sound pressure and sound power. However, the task of ascertaining the incident sound power is complicated by the sound reflection caused by the muffler. The emergence of a standing wave at the muffler inlet is depicted in Figure 3, which occurs when one-dimensional sound propagates through a duct with varying impedance. The sound pressure can be differentiated using incident and reflected spectra, abbreviated SAA and SBB, respectively. One method of dissecting the wave is by employing the two-microphone approach and the decomposition theory to partition the wave

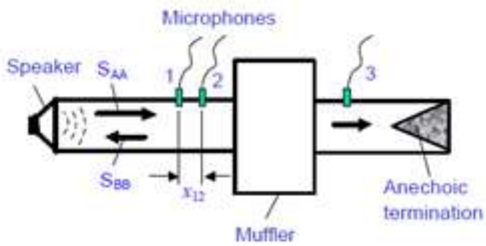


Fig3: Setup of decomposition theory

According to decomposition theory, the wave SAA's moment of inertia is

$$TL = 20\log\left[\left(\frac{Z_n}{Z_1}\right)^{1/2}\frac{(1+M_1)}{2(1+M_n)}\left|T_{11}+T_{12}/Z_n+T_{21}Z_1+T_{22}Z_1/Z_n\right|\right].$$

The level difference (LD) is also known as the lack of noise.

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

The total acoustic pressure autospectra at sites 1 and 2 are represented by S11 and S22. X12 indicates the distance between the two microphones, whereas C12 and Q12 represent the real and imaginary components of the cross spectrum between points 1 and 2. The pole factors can be used to determine the RMS amplitude of the sound pressure wave. Pic. We placed the inlet and outlet near to the ends of the pipes leading to those locations.

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

The sound strength of each wave can be determined by its amplitudes, which are the rms pressures of the wave that comes in (pi) and the wave that goes out (pt).

$$W_i = \frac{2}{\rho c^1} S \qquad (4)$$

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

In an equivalent manner. The values (4) and (5) are determined by the fluid density (s), the area of the intake and exit passages of the muffler (Si and So), and the speed of sound (c). In lieu of Equation (1), Equations (4) and (5) may be used to represent the TL.

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

Attempting to use the decomposition method with two microphones following the exhaust when the termination is not anechoic is a common error. This is ineffective due to its incongruity with the "wave sound pressure downstream" of the assault. Through decomposition, the TL for the expansion chamber depicted in Figure 2 was determined. The experiment utilized an anechoic termination with an approximate absorption rate of 0.95, operating within the frequency range of 100 to 3000 Hz. The precise results of the BEM and the TL are displayed adjacently in Figure 4. A distinct disparity can be observed in the frequency range between the values recorded and those determined by BEM. This is presumably due to the fact that the terminal region is only marginally anechoic [3].

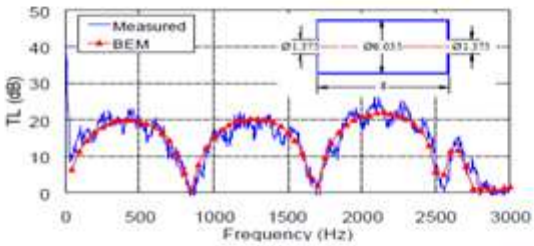
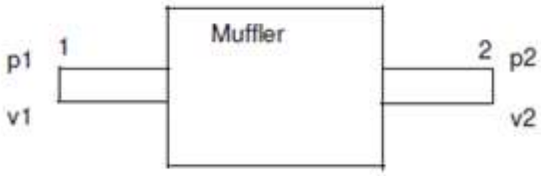


Fig4: Decomposition method vs. BEM(Muffler dimensions in inches)

The two-source approach utilizes the transfer matrix method. The composition of an acoustic element is evident from its four surfaces.

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

where v1 and v2 represent the particle velocities at those specific locations and p1 and p2 denote the sound pressures at the flow's apex and basal regions, respectively. The four-pole parameters are denoted as T11, T12, T21, and T22. Both the inlet and outlet are in close proximity to the pipe's extremities.



Coustyx accommodates two distinct muffler configurations, denoted by p1, p2, v1, and v2. An agitated source is present at the input of Configuration A, Case 1. There is a stiff egress.

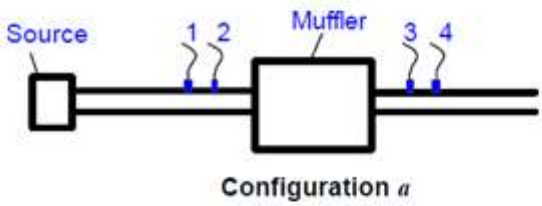


Fig6Setupoftwo-source method

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

Particles with velocities v1b and v2b are transmitted from the entrance to the exit in Configuration b (T11T22 · T12T21).As demonstrated below, the four-pole factors for pressure and velocity are subsequently solved.

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

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

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

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

In order to calculate the transmission loss of a motor, its inlet/outlet tube areas and four-pole characteristics are utilized.

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

In Figure 5, the TL ratio for the expansion chamber is illustrated in Figure 8. The two-source approach demonstrated satisfactory performance when applied to BEM data. A straight conduit filled with an absorbent material was positioned at the end [3].

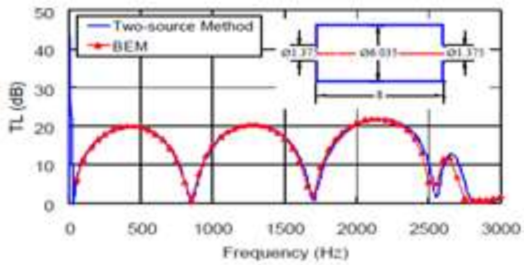


Fig8: Two-source methodvs. BEM(Muffler dimensions in inches)

B. **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

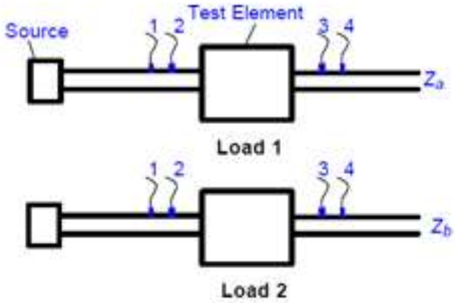


Fig9. Setup of two-load method

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 obtainedIn the two-load method, it is obvious that if two loads are verysimilar,theresultwillbeunstable.Generally,two loads can be two different length tubes, a single tube with and without absorbing material, or even two different mufflers.Inthisresearch,twoloadswereachievedbya 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 measuredusingthetwo-source method.This maybedueto the two loads not being sufficiently different in 500-1500 Hz range [3].

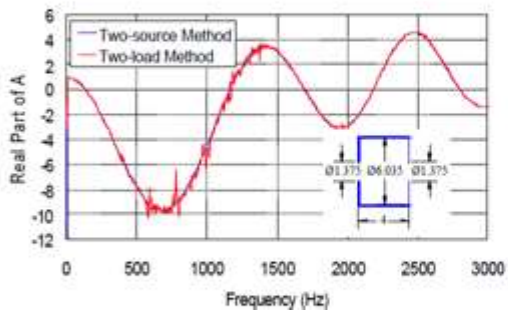


Fig10.Real part of the four pole parameter(Muffler dimensions in inches)

5.CONCLUSION

This article examines the many approaches used to estimate transmission loss. A review provides a thorough overview of the most recent approaches, their applicability to the acoustic performance approach, and the limitations of certain traditional procedures. The primary disadvantage of the decomposition approach is the need for an anechoic termination when measuring transmission loss (TL). While designing a "fully" anechoic termination is difficult, especially one that performs well at low frequencies, anechoic terminations can be achieved in practice by using lengthy exhaust ducts and highly absorbent materials. Nonetheless, alternative strategies, like as the two-source and two-load systems, have made significant contributions to accurately determining and computing transmission loss, even when an ideal anechoic termination is not present. The two-load method produces a less precise calculation of transmission loss (TL) than the two-source method, owing to the fact that the four-microphone approach uses four-pole parameters to determine parameter values. The cause was unstable when the two loads were not "sufficiently" distinct across the entire frequency range of 500-1500 Hz, as illustrated in Figure 10.As a result, the two source technique, which used the four pole transfer matrix method, generated a much more refined result and is a better option for measuring the acoustic performance of a car muffler.

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