Journal of Mines, Metals and Fuels, *71(12): 2585-2592; 2023. DOI: 10.18311/jmmf/2023/36539*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Design and Analysis of Automotive Mufflers for Noise Attenuation in Low and Broadband Frequency Range

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Abstract

Noise pollution is the major drawback of Internal Combustion engines. Automotive engineers and researchers have been working consistently on reducing automotive noise as well as pollution. While designing the mufflers, care must be taken not only for noise reduction but also for back pressure, space constraints, cost incurred, etc. Various methods to design and analyze the mufflers have been devised by researchers across the globe. In this paper an attempt has is made to present a Tuning of muffler for Low and broadband noise. Geometrical parameters influencing design of Helmholtz Muffler has been carried out in this Study. For Broadband noise, impact of Porosity and wool packing material has been chosen as a design parameter. Results observed that for exhaust system with two muffler components we have dedicated Helmholtz chamber, while for exhaust system with single muffler component, internal of muffler to have both broadband and Helmholtz integrated. Reactive mufflers like Two pass mufflers and Three pass mufflers can be taken as an initial reference to have acoustic tuning for both Helmholtz and broadband noise tuning.

Keywords: *Calotropis Procera, Ethnomedicine, Pharmacology, Phytochemistry, Tribulus terrestris*

1.0 Introduction

Acoustics for automotive industry is more critical for low frequency region. In particular, to Engine frequencies. Helmholtz concept of tuning low frequencies is one of the popular designs. Neck Diameter, Neck length and muffler Volume are the tuning elements for noise attenuation. Below relation between frequency and geometrical parameters for a provided Sound speed certainly, helps in deriving an effective muffler to tune required frequency level.

$$f_r = (c_0/2\pi)\sqrt{S_n/\{V_c(\ell_n + \delta_n)\}} \quad (1)$$

Where,

C_0 = speed of sound

V_c = resonator volume

S_n = cross-sectional area of neck

ln = length of neck

δn = end correction

Ingard[1] on circular or rectangular cross-sectional area for volume examined neck geometry effect, such as location, and size, shape, area on the resonance frequency of a Helmholtz resonator. He derived for both single and double holes to account for the higher order modes at the interface between cavity and neck end corrections.

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Chanaud[2] observed the outcome of both orifice geometry and cavity on the resonance frequency of a Helmholtz resonator using Ingard's end correction. The result of the depth and width for fixed and variable volumes was calculated. He obtained the limitations of simple lumped and transcendental models based on the predictions and concluded that for an orifice size and fixed volume, the position of the orifice changed the resonance frequency considerably, while the shape of the orifice was not significant.

Present work is on the Helmholtz resonator performance concentrates on the effect of neck extension geometry shown in Figure 1. Volume of the neck extension length will not shift the resonance frequency. Such extensions act like an additional transmission loss peak at higher frequencies compared to a resonator without extension[3]. To suppress the acoustic pulse generated by the combustion process. Internal combustion engines are typically equipped with an exhaust muffler. By combustion a high intensity pressure pulse is generated in the engine cylinder which propagates along the exhaust pipe and radiates from the exhaust pipe termination[4]. Exhaust pipe measurements using pressure pulse on an engine showed that most of the pulse energy lies in the frequency range of 0-4000 Hz. Designing of Exhaust mufflers are to reduce sound levels at these frequencies[5]. In this paper we observed for Two-pass muffler with leakage on baffle that with increase in number of perforations, Helmholtz chamber becomes transparent and acoustic waves have accessibility to adjacent volumes also. Increase in leakage will reduce the option tuning for lower frequency and complete muffler will attenuate only for broadband frequencies[6]. Muffler with calculated number of leakages on baffle, will have an advantage of attenuating both low (Helmholtz design) and broadband frequencies

There are a number of methods currently used to model and investigate the performance of mufflers.

- Analytical Method.
- Transfer Matrix Method (TMM).
- Numerical Method.
- Boundary Element Method.
- Experimental method for measuring TL.

Transmission Loss (TL): Transmission Loss is the ratio of the incident power and transmitted power. Transmission Loss is typically a basic way to explore the tuning elements of a provided muffler with its internals on spectrum of frequency.

$$TL = 10 \log(Wi/Wt)dB \quad (2)$$

Where,

Wi = incident acoustic power

Wt = transmitted acoustic power

2.0 Assumptions Made for 1-D Calculations

Based upon the 1D plane wave equation and empirical formula of Transmission Loss (TL) Analytical calculations

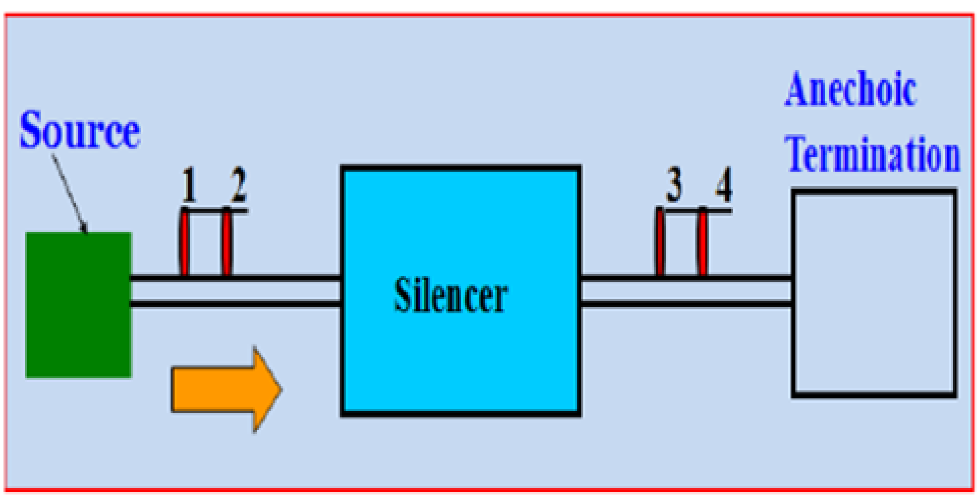


Figure 1. Concept picture of Transmission Loss.

are made[7]. At the region of discontinuities particle velocity and pressure continuity equations are used[8].

The following assumptions are considered for this analysis-

- The sound propagation is plane wave theory and one direction only.
- Assumed Sound propagation in a stationary medium.
- The mean pressure and mean density are uniform and steady throughout the fluid.
- Fluctuating pressure or Acoustic is the additional pressure from the mean pressure.
- Relatively to small acoustic pressures Analysis is limited so that the changes in density are compared with the mean density.

3.0 Objective of the Present Study

Objective of the present study is to carry out acoustic attenuation in a stationary medium for the following variants of muffler.

- With *an extended neck* concentric circular Helmholtz resonator and effects of neck *length* extension on the resonator behavior.
- 2-Pass muffler with Helmholtz chamber and impact of varying leakage on baffle.

4.0 Numerical Methodology

GT-Power software is used for Transmission Loss simulation of a muffler. This software is used for design and development of IC Engines[9]. It has a good device library to model after treatment devices. This software has complete flexibility to modify the mechanisms. On all aspects of engine simulations can be done. GEM3D is a tool used for 3D modeling. Layout of Transmission Loss in GT-Power is shown in Figure 2.

The model begins with an 'End Flow Speaker' object, which generates a periodic signal of random noise. It references a driver which defines the base frequency and the number of degrees per cycle in the simulation. A pipe is downstream of the speaker where the upstream pressures are sensed for the transmission loss calculation[10]. After that is a sub-assembly component. The muffler sub-assembly file is referenced in that part (which is the muffler1.gtm file that also exists in the Muffler directory). Downstream from the sub-assembly is another pipe, where the downstream pressures are sensed for the transmission loss calculation. After the pipe is an 'End Flow Anechoic' part, which absorbs all pressure pulses that reach it, which models the conditions used in actual tests[11,12]. The transmission loss calculations are made by the 'Acoustic Trans Loss' object, which senses the pipe pressures through 'Sensor Conn' objects. Since this

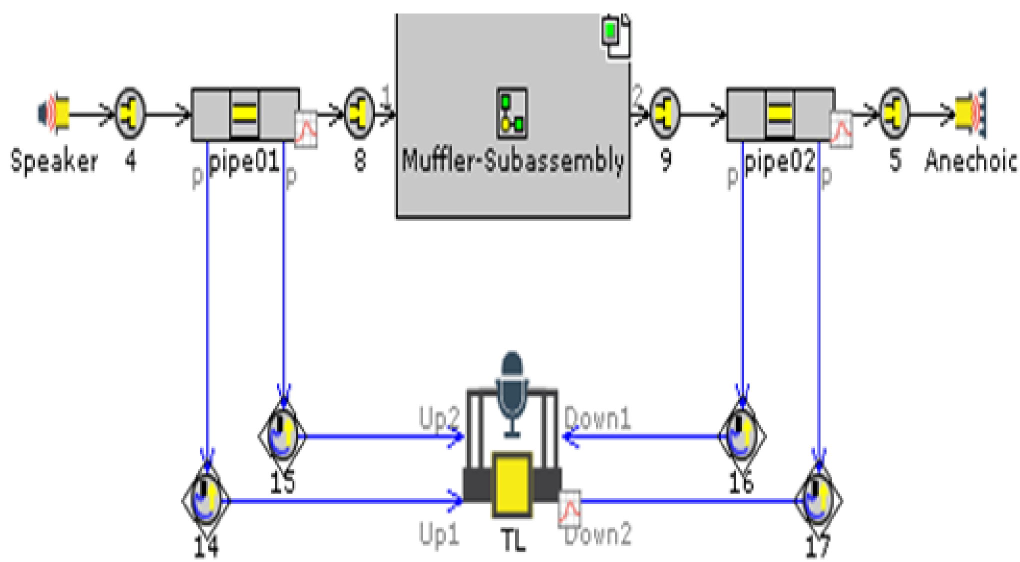
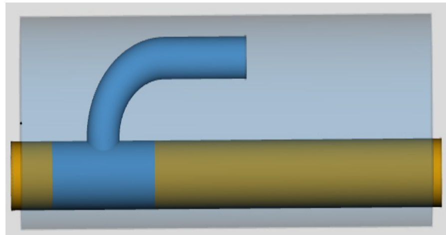
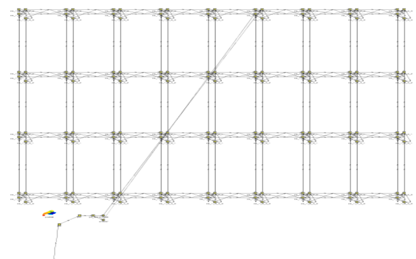


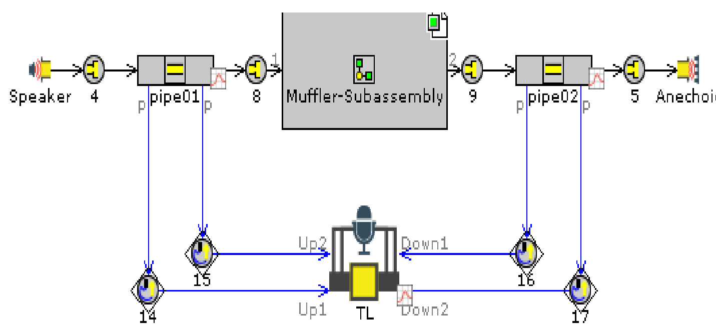
Figure 2. Layout of Transmission Loss in GT-power.



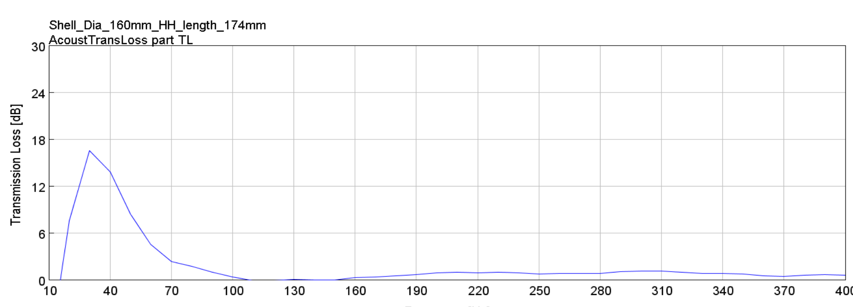
Build Muffler Model



Discretized Muffler Model



Integrate Discretized Muffler model in Problem setup



Transmission Loss results from GT-Post module (Post-Processing)

Figure 3. Flow chart of GT-post module.

model uses a subassembly for the muffler, it can be used as a template for transmission loss simulations, where the sub-assembly can be switched easily from one muffler model to another. The flowchart of GT-post module shown in Figure 3, Varying diameter of Helmholtz neck shown in Figure 4, Transmissions loss v/s frequency (Shell diameter 160 mm to 174 mm HH length) shown in Figure 5, 2-Pass Muffler with Neck Length = 100mm shown in Figure 6, 2-Pass Muffler with Neck Length = 200 mm shown in Figure 7, 2-pass muffler with different neck length impact and neck length on tuning of peak frequency shown in Figure 8, and Two-pass muffler with leakage on baffle shown in Figure 9.

5.0 Results and Discussion

5.1 Helmholtz Design

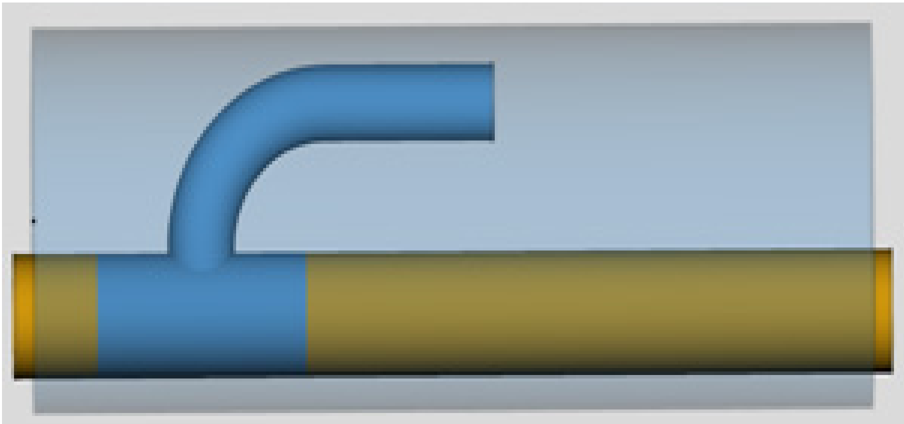


Figure 4. Varying diameter of Helmholtz neck

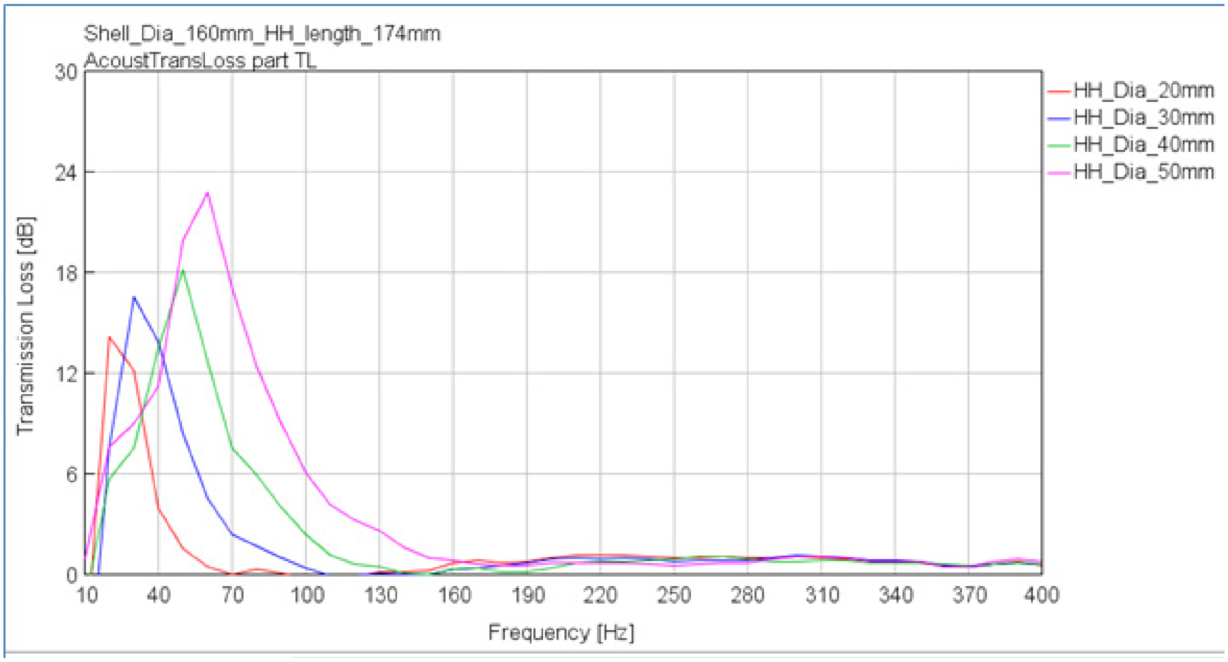


Figure 5. Transmissions loss v/s frequency (Shell diameter 160 mm to 174 mm HH length).

Shell Diameter = 160 mm, Neck Length = 174 mm

5.2 2-Pass Muffler

Shell Diameter = 160 mm, Neck Diameter = 30 mm, Total Volume = 8 Liters. Baffle is placed at 130 mm from inlet. Perforation Diameter = 3 mm, porosity = 30%, Perforation length = 60 mm.

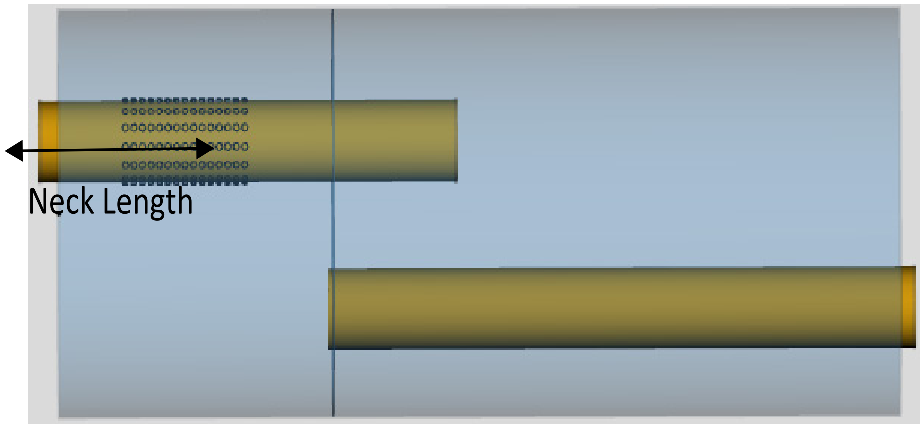


Figure 6. 2-Pass Muffler with Neck Length = 100mm

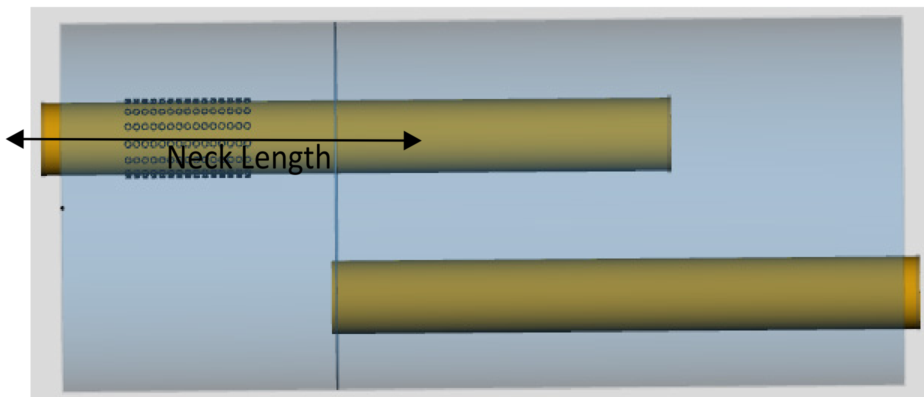


Figure 7. 2-Pass Muffler with Neck Length = 200 mm.

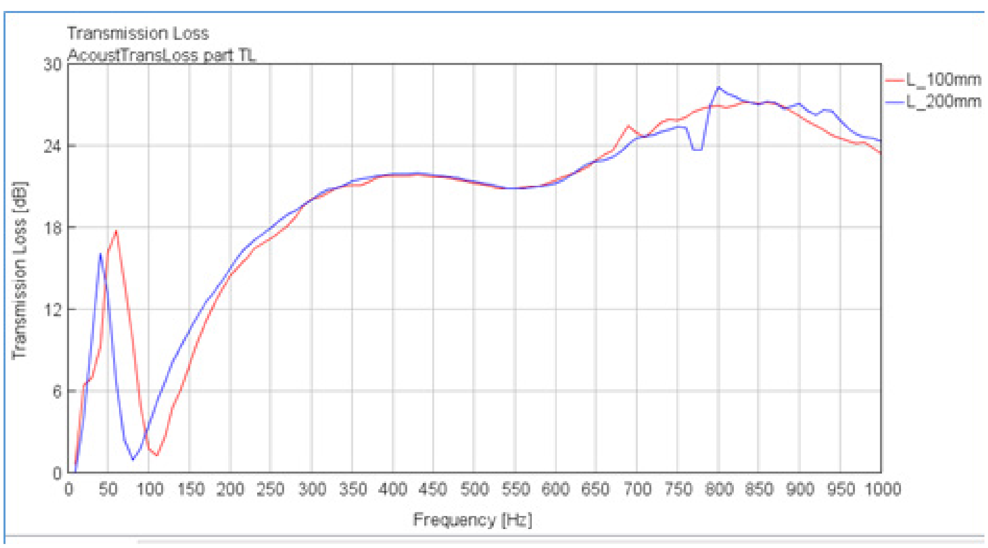


Figure 8. 2-pass muffler with different neck length impact and neck length on tuning of peak frequency.

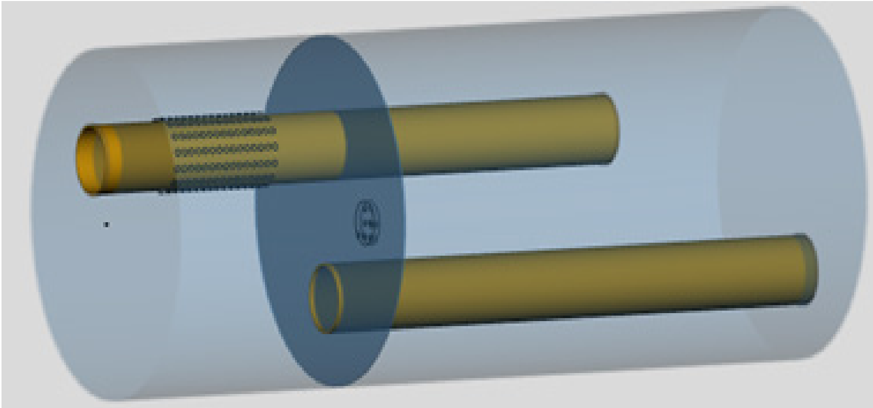


Figure 9. Two-pass muffler with leakage on baffle.

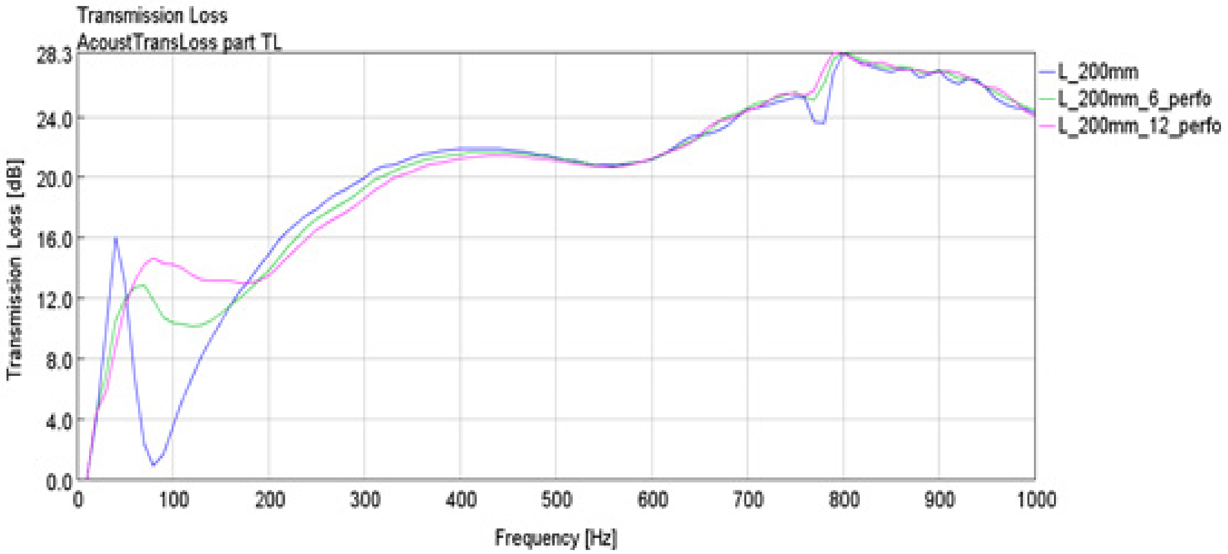


Figure 10. Two-pass muffler with leakage on baffle.

Table 1. Varying neck diameter Vs peak frequency attenuated

Pipe Diameter, mm	Peak frequency, Hz
20	20
30	30
40	50
50	60

From the above Figure 8, we observe that reducing neck length enables tuning for low frequencies. Increased length of pipe decreases volume available for attenuation. Two-Pass muffler works as a Hybrid muffler having option of tuning particular frequency (Helmholtz) and also broadband frequency.

From the above Figure 10, we observe that with increase in number of perforations, Helmholtz chamber becomes transparent and acoustic waves have accessibility to adjacent volumes also. Increase in leakage will reduce the option tuning for lower frequency and complete muffler will attenuate only for broadband frequencies. Muffler with calculated number of leakages on baffle, will have an advantage of attenuating both low (Helmholtz design) and broadband frequencies.

6.0 Conclusion

- Virtual Simulation is an integrated part of Product development cycle. Present paper provides

a guideline to tune muffler for both low and broadband noise levels.
- Hybrid mufflers (Helmholtz + reactive mufflers) has an advantage of Muffler Volume saving, reduction of weight and cost.
- Reducing neck length enables tuning for low frequencies. Increased length of pipe decreases volume available for attenuation.
- Two-Pass muffler works as a Hybrid muffler having option of tuning particular frequency (Helmholtz) and also broadband frequency.
- With increase in number of perforations, Helmholtz chamber becomes transparent and acoustic waves have accessibility to adjacent volumes also.

7.0 Summary

Under floor space of an automotive vehicle will be limited to have more muffler volume or for optimized pipe routing. However, with these limitations exhaust system needs to meet noise level target to meet Pass-by noise regulations. Design constraints like space, Noise regulations, cost, accessibility to tools for maintenance, low weight for better fuel economy, pressure drop Target for exhaust system motivates to explore more on design space inside the available muffler volume.

In this paper, discussed advantage of having standalone Helmholtz muffler with a Two-Pass (Hybrid) muffler. Hybrid muffler with leakage on baffle has an advantage of designing both low and broadband noise levels. By carefully considering above factors, a mining department can choose and implement automotive mufflers that not only meet regulatory requirements but also contribute to a quieter, safer and more sustainable mining operation.

8.0 Scope of Future Work

Transmission Loss study is of a Source independent study. Once source (Engine acoustic characteristics) is available, need to work on Insertion loss to save time and have a comparative impact of muffler internals on noise levels. Once optimized muffler is derived from Insertion loss calculations, we can carry out Tailpipe Noise simulation for final evaluation of Noise levels for different engine speeds.

9.0 References

1. Ingard U. On the theory and design of acoustic resonators. The Journal of the Acoustical Society of America. 1953; 25(6):1037-1061. https://doi.org/10.1121/1.1907235
2. Chanaud RC. Effects of geometry on the resonance frequency of Helmholtz resonators. Journal of Sound and Vibration. 1994; 178(3):337-48. https://doi.org/10.1006/jsvi.1994.1490
3. Tang PK, Sirignano WA. Theory of a generalized Helmholtz resonator. Journal of Sound and Vibration. 1973; 26(2):247-62. https://doi.org/10.1016/S0022-460X(73)80234-2
4. Dickey NS, Selamet A. Helmholtz resonators: one-dimensional limit for small cavity length-to-diameter ratios. Journal of Sound and Vibration. 1996; 3(195):512-7. https://doi.org/10.1006/jsvi.1996.0440
5. Selamet A, Radavich PM, Dickey NS, Nova JM. Circular concentric Helmholtz resonators. The Journal of the Acoustical Society of America. 1997; 101(1):41-51. https://doi.org/10.1121/1.417986
6. Selamet A, Ji ZL. Circular asymmetric Helmholtz resonators. The Journal of the Acoustical Society of America. 2000; 107(5):2360-2369. https://doi.org/10.1121/1.428622 PMid:10830358
7. Cheng CR, McIntosh JD, Zuroski MT, Eriksson LJ. US Patent No. 5,930,371. Washington, DC: U.S. Patent and Trademark Office; 1999
8. Munjal ML. Acoustics of ducts and mufflers with application to exhaust and ventilation system design. John Wiley & Sons; 1987.
9. Yasuda T, Wu C. Predictions experimental studies of the tail pipe noise of an automotive muffler using a one dimensional CFD model. Appl Acoust. 2010; 71(8):701-7. https://doi.org/10.1016/j.apacoust.2010.03.001
10. Fu J, Chen W, Tang Y, Yuan W, Li G, Y. Li Modification of exhaust muffler of a diesel engine based on finite element method acoustic analysis. Adv Mech Eng. 2015; 7:1-11. https://doi.org/10.1177/1687814015575954
11. Kashikar A, Suryawanshi R. Development of muffler design and its validation. Applied Acoustics. 2021; 180. https://doi.org/10.1016/j.apacoust.2021.108132
12. Kalita U, Singh M. Optimization of a reactive muffler used in four-cylinder petrol engine into hybrid muffler by using CFD analysis. Materials Today Proceedings. 2022; 50(5):1936-45. https://doi.org/10.1016/j.matpr.2021.09.319