

Design, Analysis and Optimization of a Single-Pass Straight Pipe Resonator for an Exhaust System of a Single Cylinder Engine



Omkar Samant, Gulammoin Kasmani, Jay Saple, Jayraj Ranade, and Vinit Katira

Abstract The purpose of this research was to design a method to attenuate exhaust sound waves within a specified frequency range, in an exhaust system of an internal combustion engine for a formula-type car by resonance. A resonating chamber was designed along with the muffler that targets the frequency range of the exhaust sound. The engine data obtained through dynamometer was used as an input to Ricardo WaveBuild software which provided the data and was further analyzed by a fast Fourier transform model. The resonating chamber design was finalized after iterations of the same which were tested virtually for their transmission loss. The parameters such as location and orientation of exit pipe, length of perforation (internal structure) start and the distance between holes were observed to have a significant effect on transmission loss.

Keywords Resonator · Sound · Frequency · Reflective · FFT analyzer · Muffler · Exhaust · Noise · Ricardo · Wave

1 Introduction

Designing of an exhaust system requires understanding about its effect on output of an engine and noise attenuation. Thus, a sound knowledge in the fields of internal combustion engines, fluid mechanics and acoustics is essential. At the same time, the rules imposed by FSAE competition needs to be taken into consideration. Sonal [1] observed that the engine exhaust noise originates from the exhaust tailpipe openings and is transmitted through the cabin walls, firewall and nose gear bay. Various parameters such as transmission loss, back pressure to the engine due to the restriction of the flow, insertion loss required and available space must be taken into consideration before designing an exhaust system. Since the prime motive was to design a car for the Formula SAE events, the rules prohibit use of absorptive or hybrid mufflers. Therefore, this research is limited to the design and analysis of reactive muffler and

O. Samant (✉) · G. Kasmani · J. Saple · J. Ranade · V. Katira
Dwarkanadas J. Sanghvi College of Engineering, Mumbai, India
e-mail: omisamant@gmail.com

© Springer Nature Singapore Pte Ltd. 2020
H. Vasudevan et al. (eds.), *Proceedings of International Conference on Intelligent Manufacturing and Automation*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-4485-9_61

resonator. The volume flow rate, internal diameter of the pipe and other parameters were calculated on the basis of the approach specified by Rahul [2]. Simply by putting a reflective obstacle at a distance of $n/4$ like Shubham et al. [3]. We considered making tunable resonator, but there was a considerable risk of leaking. A tunable resonator is the one whose length can be varied by using a piston that can be set at different positions. The expansion chambers and perforated pipes were designed to relieve back pressure, and the muffler is tested on SimScale GmbH. Multiple design iterations were carried out, and the optimum design was chosen which was then tested on Ricardo WaveBuild software to analyze the acoustics of the exhaust system. The maximum attenuation occurs when $L = n/4$ as reported by Shubham et al. [3]. Testing procedures that Sonal [1] carried out tests by measuring sound pressure level at four locations fixed by making a rig [resonator], measured the noise at different settings of the resonator. Doige and Thomas [4] measured the noise at two locations across the muffler elements. It was decided to perform the noise test before and after installation of the resonator in order to observe the noise attenuation. The frequency log is obtained with and without the resonator to compare it with the original data.

2 Design

The resonator acts like a buffer for the muffler in exhaust system. It is not the actual muffler; hence, it should be designed keeping that in mind. The resonator is a chamber which has a pipe running throughout its length. The pipe running through the resonator has perforations so as to allow air to expand in this chamber considerably and then move on. This expansion helps in noise minimization if the length and diameter of the resonator are kept such that the waves of the desired frequencies are dampened. Since a large magnitude of sound reduction, i.e., 30 dB, is required, a more intricate and effective resonator had to be designed. After some iterations of distance of start of perforation from inlet end, perforation size, etc., the final design is shown in Fig. 1.

Fig. 1 Resonator design after performing multiple iterations

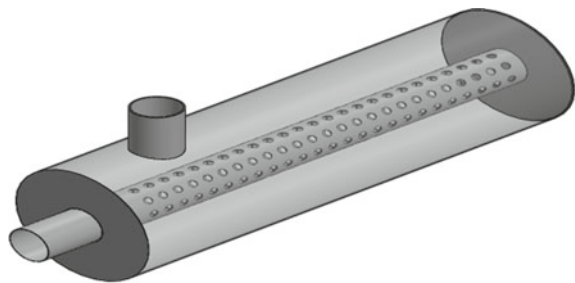
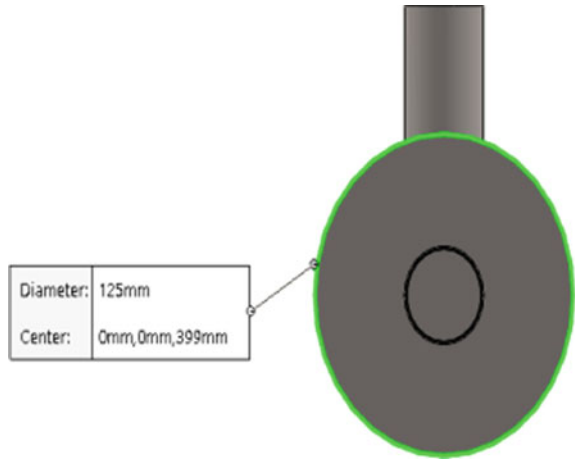


Fig. 2 Resonator can diameter



3 Theoretical Analysis and Calculations

The simplest way to produce a wave of opposite phase is to put a reflective obstacle at a distance of $n\lambda/4$, where $n = 1, 3, \dots$ other odd integers. A value of $n = 1$ has been used in the design. And the frequency range is taken from 180 to 500 Hz.

The wavelength λ corresponding to frequency 180 Hz = $V_s/f = 1.83$ m and the wavelength λ corresponding to frequency 500 Hz = $V_s/f = 0.66$ m.

Maximum length of resonator cylinder $L_{\max} = \lambda/4 = 0.458$ m.

Minimum length of resonator cylinder $L_{\min} = \lambda/4 = 0.165$ m.

Length of tuning of resonator is given by $L_{rt} = L_{\max} - L_{\min} = 0.29$ m.

The Resonator Pipe ID was kept 35 mm and OD 37 mm which was similar to the exhaust runner. Each perforated hole had a diameter of 7 mm and distance between two holes was kept 14 mm with eight holes making a circular pattern on the circumference of the pipe. The perforation starts at 44 mm from inlet end all the way till the end. Outlet pipe was 52 mm from one end of the resonator as shown in Figs. 2, 3, 4 and 5.

4 Simulations

There are two types of simulations carried out, and they are as follows:

1. Ricardo wave software simulations to determine the transmission losses in different designs of resonators.
2. CFD analysis on SimScale software to validate the flow of gases inside the resonator and to examine the pressure and velocity variations inside the resonator.

Fig. 3 Resonator can length

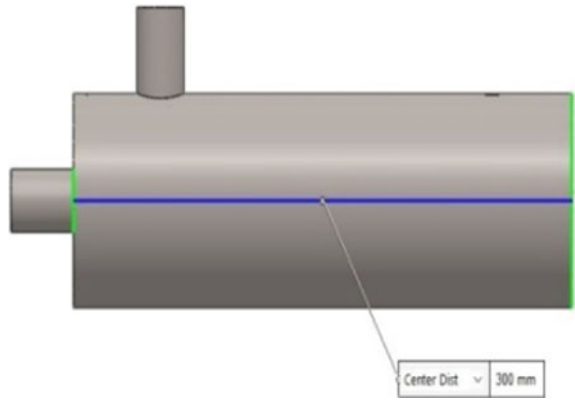


Fig. 4 Perforations dimensions

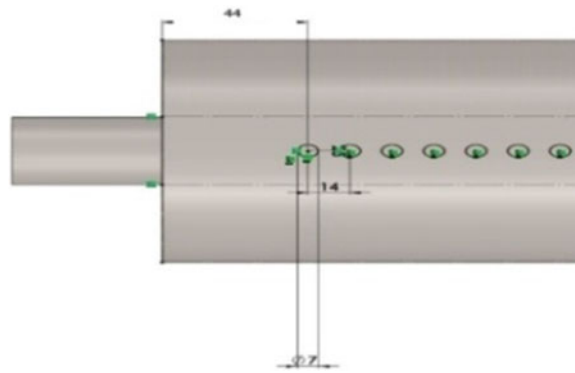
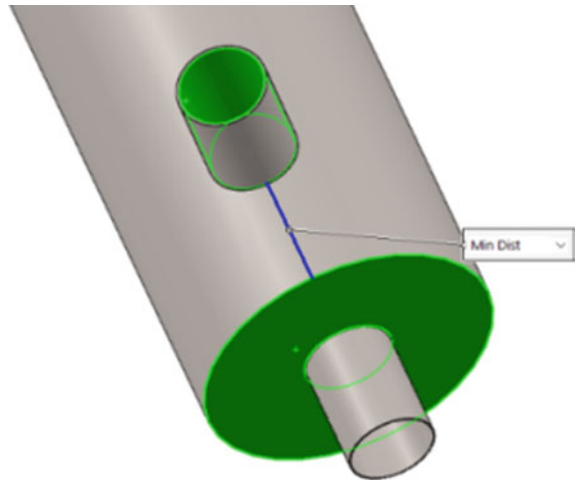


Fig. 5 Distance from inlet



4.1 Ricardo Simulation

4.1.1 Engine Plot on Ricardo WaveBuild

A virtual engine dynamometer helps to compute the dB level for the exhaust system. The engine model was created on Ricardo wave along with the complete intake and exhaust system. The WaveBuild model was used to find out the acoustic data required for designing an exhaust system. A pressure sensor was placed just near the exhaust port which was used to collect real-time pressure data in the exhaust runner as shown in Fig. 6. This data was used to extract an audio file from Ricardo Wave-Post.

The extracted audio file created using the pressure sensor was analyzed in FFT analyzer (DSSF3), and SPL versus frequency graphs were obtained as shown in Fig. 7. The analyzer was set to dB(c) and fast weighing. The sampling rate was set the same as the audio file.

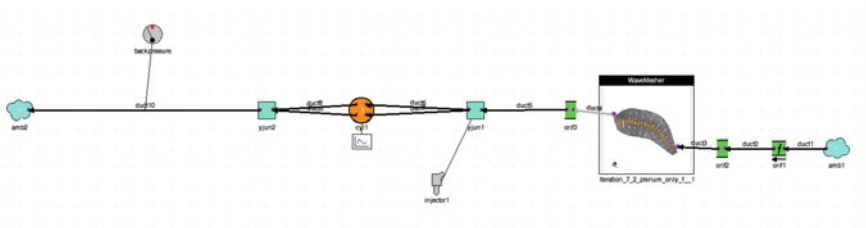


Fig. 6 Engine plot on WaveBuild

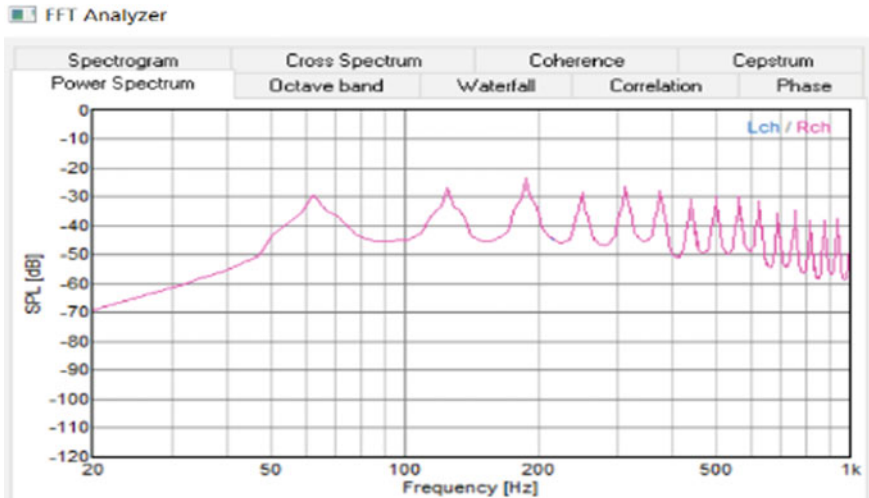


Fig. 7 SPL versus frequency graph

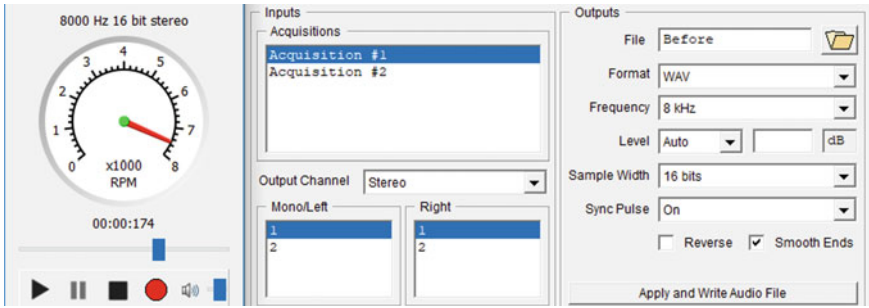


Fig. 8 Input to FFT analyzer

It was observed from the above plots that the peaks in the range of 180 and 500 Hz are to be attenuated, so resonator design was iterated to get the desired transmission loss (Fig. 8).

4.1.2 WaveBuild 3D

The most optimum design represented in Fig. 9 was chosen for the following reasons:

- 1. Nearly 20 dB transmission loss
- 2. No nodes in the range of operation
- 3. Routing and packaging are better.

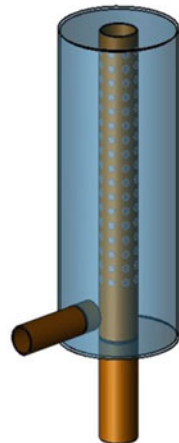
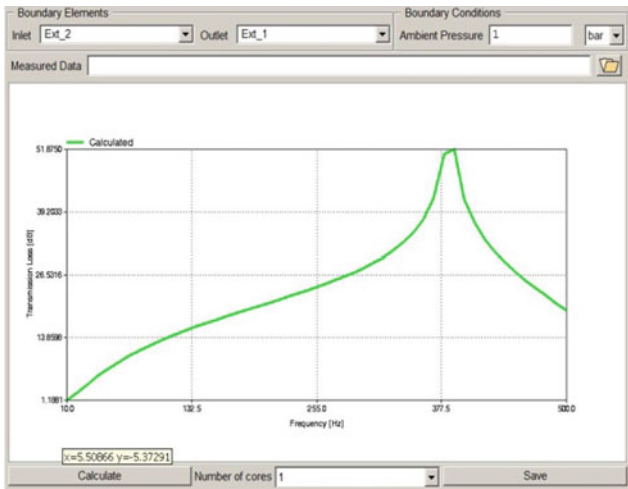


Fig. 9 Iteration 1

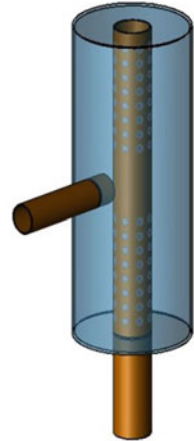
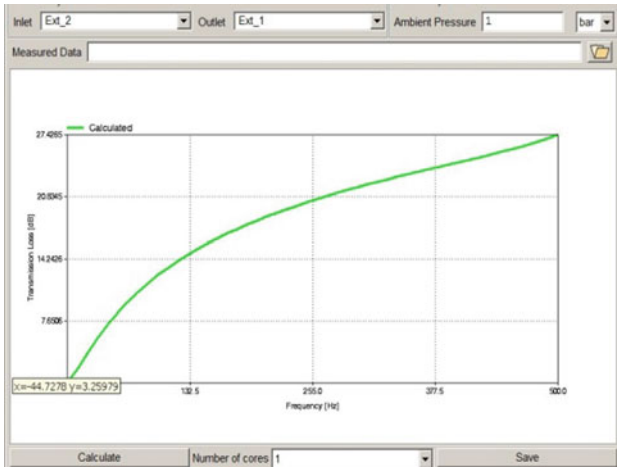


Fig. 10 Iteration 2

The resonating chamber design was finalized after iterations of the same which were tested virtually for their transmission loss. The parameters such as location and orientation of exit pipe, length of perforation (internal structure) start and the distance between holes were observed to have a significant effect on transmission loss (Fig. 10).

4.2 *CFD Analysis on SimScale*

A bounding box was also specified to generate an accurate mesh. After meshing, the analysis type was chosen. Incompressible type of analysis was done, and k-omega, SST turbulence model was chosen. The pressure at inlet of resonator and mass flow rate at outlet of muffler and wall were the three boundary conditions used for analysis as shown in Figs. 11, 12, 13 and 14. The simulated results of pressure drop and velocity variations are shown in Fig. 15.

The design represented was finalized due to the following reasons:

1. This design gives the highest pressure drop between inlet and outlet.
2. This design gives almost constant velocity between inlet and outlet.

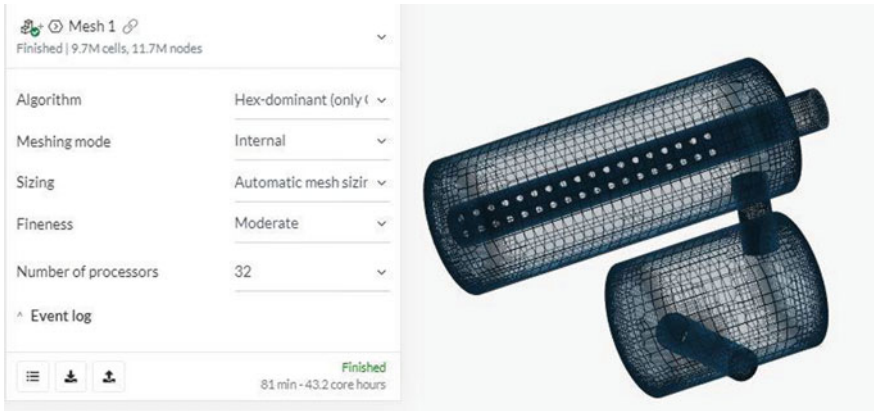


Fig. 11 Mesh size

Fig. 12 Analysis type

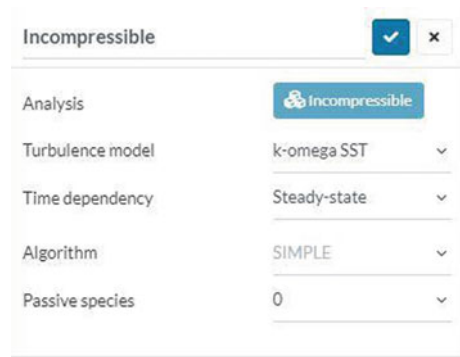


Fig. 13 Velocity condition

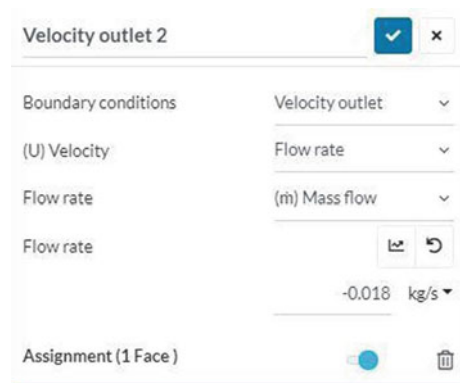
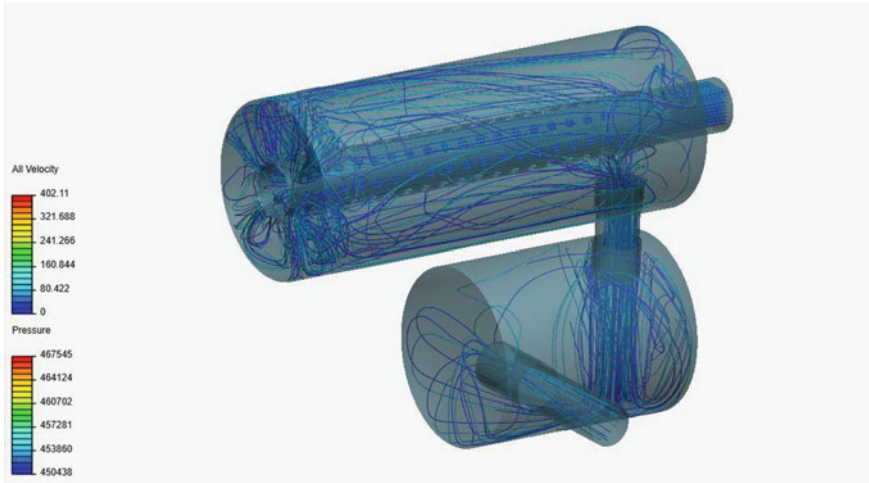


Fig. 14 Inlet pressure**Fig. 15** Analyzed results

5 Experimental Analysis

5.1 Test Procedure

1. The test was carried out with the engine mounted on the chassis of car as shown in Fig. 16. The gaseous emissions from the exhaust of the engine include hydrocarbons, carbon monoxide and oxides of nitrogen.
2. During a prescribed sequence of warmed up engine operating conditions, the amounts of the above gases in the exhaust shall be examined continuously. The prescribed sequence of operations consists of a number of speed and power modes which span the typical operating range of petrol engines.
3. During each mode, the concentration of each pollutant, exhaust flow and power output shall be determined and the measured values weighted and used to calculate the noise level of the resonator.



Fig. 16 Experimental Test Setup

Table 1 Comparison of results

Condition	Noise level (experimental) (dBC)	Noise level (designed) (dBC)
At 3100 rpm	102.8	103
At 7500 rpm	112.4	110

5.2 Test Results

The experimental results were compared with the simulated results at idling rpm and at 7500 rpm. The obtained experimental results are shown in Table 1.

6 Conclusion

The exhaust resonator designs were iterated to obtain the most optimum design on the basis of maximum pressure drop and sound minimization. The selected design was simulated using Ricardo WaveBuild and SimScale software packages. The selected design was fabricated, and its performance parameters were obtained. The exhaust sound attenuation results obtained from the experimental tests were compared with simulated results and were observed to be in a good agreement. The difference between the two experimental and simulated values could be attributed to the uncontrollable parameters like the temperature of surrounding, wind speed, localized pressure differences, calibration of decibel meter, etc.

References

1. Jebanski R. Absorption mufflers in exhaust systems
2. Nazirkar CD, Meshram SR, Namdas AD, Navagire SU, Devarshi SS. Design and optimization of exhaust muffler and design validation
3. Pal S, Golan TS, Kumar V, Jain V, Ramdas N, Sharma OP. Design of a muffler & effect of resonator length for 3 cylinder SI engine
4. Panicker VB, Munjal ML. Aeroacoustics analysis of straight through mufflers with simple and extended tube expansion chambers
5. Potente D. General design principles for an automotive muffler
6. Zakhmi S. Study of noise generated by single cylinder two stroke petrol engine
7. Parrott TL. An improved method for design of expansion-chamber mufflers with application to an operational helicopter
8. Gupta AK, Tiwari A. Performance of transmission loss on hybrid muffler by using rock wool and glass fiber as absorbing materials
9. 2019 Formula SAE Rules. SAE International