Acoustics and Flow Field Analysis of Perforated Muffler Design

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***Abstract* - In today's world where the technologies are emerging at high speed and also new regulations and standards for noise emission increasing in the automotive firms and hence there is need to think over the current working system for the noise reduction or to make some improvements about decreasing the engine noise. Nowadays, the perforated reactive mufflers which have an effective damping capability are specifically used for this purpose. In this work new designs should be analyzed with respect to both acoustics and back pressure. In this study, a reactive perforated muffler is investigated numerically, experimentally and by the analysis. For an acoustical analysis, the transmission loss which is independent of sound source of the present cross flow, the perforated muffler was analyzed. To be able to validate the numerical results, transmission loss was measured experimentally. Back pressure was obtained based on the flow field analysis and was also compared with experimental results. Numerical results have an approximate error of 20% compared to experimental results.**

***Keywords* - Acoustics, Back Pressure, Perforated muffler, Transmission loss.**

I. INTRODUCTION

In today's competitive market new regulations and standards for noise emission increasing at high rate especially in the automotive firms hence it must to make some improvements in decreasing the engine noise. Hence the designs of various types of the mufflers which have an effective damping capability are specifically used for this purpose. The acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquid and solids including vibration, sound, ultrasound and infrasound. The study of acoustics revolves around the generation, propagation and reception of mechanical waves and vibration. There are many kinds of transduction process that convert energy from some other forms in to sonic energy, producing a sound wave. The Sound Intensity is the rate of energy flow through a unit area and it is averaged product of pressure and particle velocity.Mean energy associated with sound waves is its fundamental feature and the particle velocity is sinusoidal to and fro movement of particles,

u = Sound pressure / acoustic impedance.

Table 1- pressure range [1]

Sound pressure in N/m^2	Sound pressure in dB	Implication
0.00002	0	Threshold of hearing
20	140	Sensation of pain

The atmospheric Pressure is $10^5 N/m^2$. The decibel scale is used for sound intensity measurement and for that the threshold of hearing is used as reference pressure. The decibel scale is then defined by comparing the sound pressure to reference sound pressure.

The sound pressure level (SPL) is given by,

$$(SPL)Lp = 10 (\log p^2/p0^2) \text{ (dB)} \qquad (1)$$

The dominating method of measuring sound intensity in air is based on the combination of two pressure microphones. However, a sound intensity probe that combines an acoustic particle velocity transducer with a pressure microphone has recently become available [2].

II. MODEL BUILDING

CAD model of the present muffler which will be examined in this paper as shown in Fig. 1 the muffler consists of perforated inlet and outlet pipes and two perforated baffles. The perforate rates of inlet and outlet pipes are approximately 30% and 12%, respectively. Furthermore, the muffler has three expansion chambers. Perforated parts of inlet and outlet pipes create a cross flow inside the muffler.

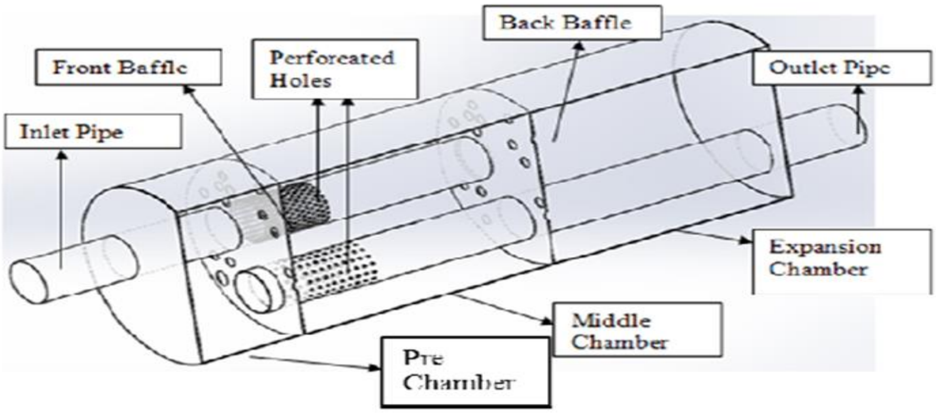

Fig.1: present CAD model

Numerical Calculation

In this study, acoustic and flow characteristic of the present muffler were analyzed and the simulation results were compared with experimental results.

III. ACOUSTIC ANALYSIS ACOUSTIC MEASUREMENTS

As mentioned earlier, acoustic characteristics of a muffler can be determined with transmission loss. For this purpose, numerical simulations of the transmission loss of the present muffler were performed with COMSOL. In this calculation, the mean flow of the muffler was ignored. The geometry of the muffler was drawn with the same program. The straight and perforated parts of the pipes were drawn separately and perforate rates were entered into the program. For perforated baffle, holes were not drawn separately; holes were drawn as they will have approximately the same center of gravity. Inlet and outlet parts of the muffler were chosen on the program. The muffler was mesh automatically with tetrahedral elements. Minimum wavelength of a muffler is 0.327 acoustic examination, mesh size must be smaller than 1/6 of the wavelength. Thus, a mesh size of 0.019 modeled muffler. In this program, sound pressure, p, was calculated by Helmholtz equation,

$$\nabla.\left(\frac{1}{\rho 0}\nabla p - q\right) + \frac{k2}{\rho o} = 0 \qquad (2)$$

Where, k=2πf/c0 is the wavelength, ρ0 is the density of the fluid and c0 is the sound speed. q Is two pole source terms which means acceleration per unit volume and equals to 0 in this study. With this expression, a solution on frequency domain can be found using a parametric solver.

Transmission Loss expression found out to be,

$$TL = 10\ log\ \frac{Pin}{Pout} \qquad (3)$$

Where, Pin and Pout denote acoustic effects on inlet and outlet of the muffler, respectively. These acoustic effects are calculated with (4) and (5) as below,

$$Pin = \int \frac{Px^2}{2\rho c0}\ dA \qquad (4)$$

$$Pout = \int \frac{/pc2/}{2\rho c0}\ dA \qquad (5)$$

These equations were given to the programs as variables and pressure Po set to be 1 bar.

3-D drawing of the geometry and the meshed geometry shown in Figs.

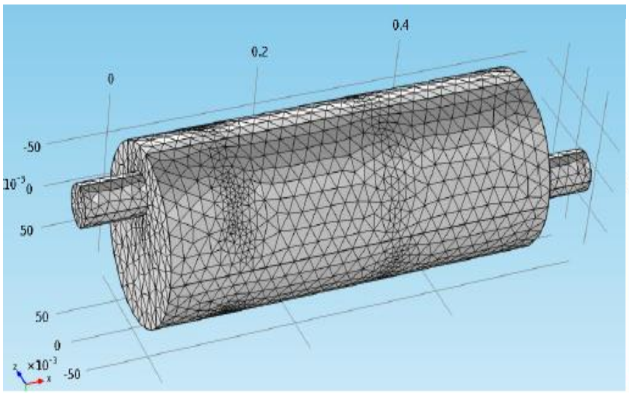

Fig.2 3D drawing of geometry [8]

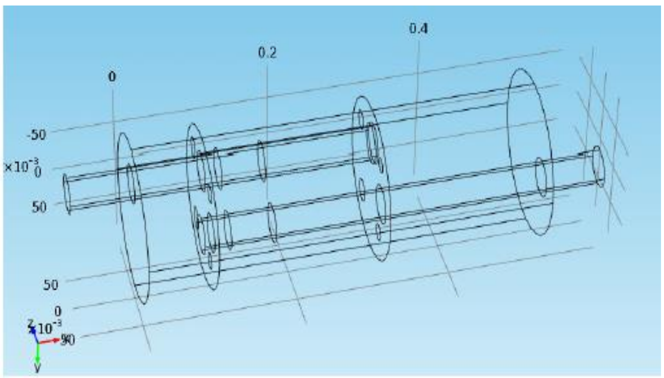

Fig.3 Meshed geometry [8]

Flow Field Analysis

For flow analysis of the muffler, present muffler was drawn via a 3D CAD program. This 3D muffler model was meshed using Ansys Workbench with Tetrahedral elements. Since the muffler has a small wall thickness and small dimensions and especially the part of perforated holes causes problems during mesh generation, thus, hexagonal mesh was not used.

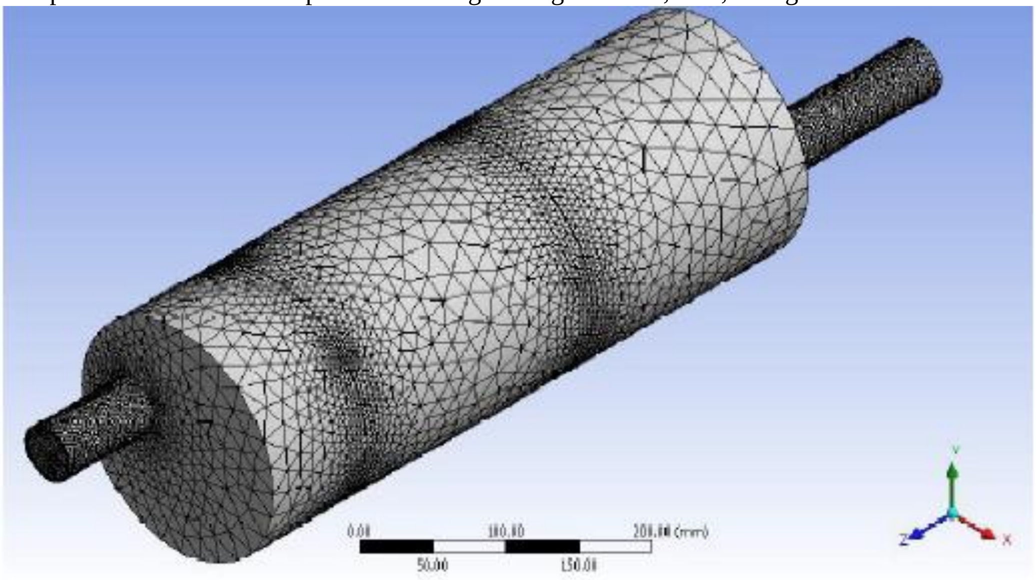

Fig.4. Mesh of muffler geometry [8]

After the muffler was meshed, flow field analysis was performed with Fluent. The flow inside the muffler is assumed to be turbulence, so k- ε turbulence model was used in this study. Since the density is expected to change with temperature, energy equation was also solved in the program. Velocity and temperatures were defined as inlet boundary conditions. Pressure and temperature were defined as outlet boundary conditions; the physical properties of air were defined for flow analysis. Boundary conditions are given in Table 2. The simulations were performed for five different Inlet velocities, namely, 23, 46, 70, 93, and 116m/s.

Table 2: Boundary conditions provided [9]

Sr. No.	Parameter	Values
01	Inlet Temperature	473 K
02	Inlet Turbulence Density	10%
03	Inlet Hydraulic Diameter	0.0434 m
04	Outlet Pressure	101325 Pa
05	Outlet Temperature	343 K
06	Outlet Turbulence Density	10 %
07	Outlet Hydraulic Diameter	0.0434 m

Experimental Data

In the experimental set up, white noise signal produced by analyzer is transmitted to the source of the sound in order to generate the needed sound by amplifier. White noise which is generated by source is sent to the muffler.

IV. ACOUSTIC MEASUREMENTS

Transmission loss is the rate of sound pressure level incoming and outgoing from the muffler. It was expressed on frequency domain. Transmission loss is independent from the source and depends on the structure of the muffler. Equipments used for measuring transmission loss are:

- 4-Channel FFT Analyser
- Pressure type microphone
- Power amplifier
- Adapter and connection pipes
- Sound source

Experimental setup and equipment are shown in Fig. 5. With four microphones that are placed in inlet and outlet of the muffler, sound pressure signals are collected during a period of time and these signals are converted to frequency domain with FFT after being amplified, and as a result auto-spectrum and cross spectrum values are obtained.

These data taken from the analyzer is processed by the computer and the transmission loss curves are obtained.

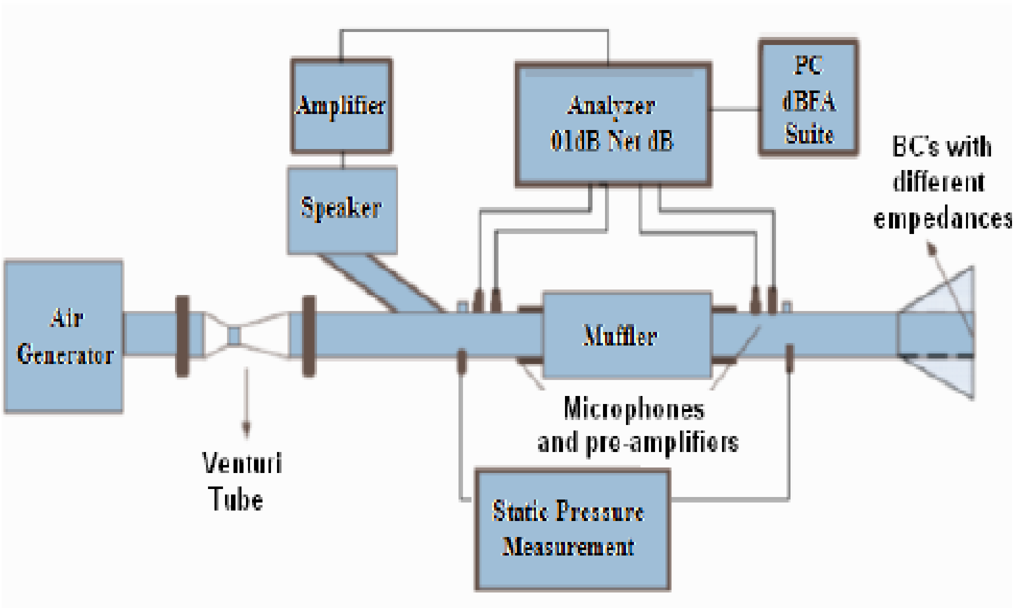

Figure 5: Experimental set up

Flow Measurement

By measuring pressure at inlet and outlet of the muffler, pressure loss can be obtained at specific air flow rate. For this purpose, pressures sensors were placed at the experimental setup as shown in Fig. 5. While the transmitted signal was processed, it was delivered to the digital screen. A blower connected to a motor was used to provide air and this blower was controlled with an AC frequency converter. The muffler was attached to the blower and pressure values were recorded.

V. DISCUSSION ON RESULTS

The comparison of experimental and numerical transmission loss results of the present muffler are shown in Fig.6. It is commonly known that reactive mufflers are more effective in low frequency bandwidth. The cut-off frequency of the present muffler is approximately calculated as 1040Hz with the equation of $fc=1.84c/(\pi d)$, where fc is the cut off frequency,

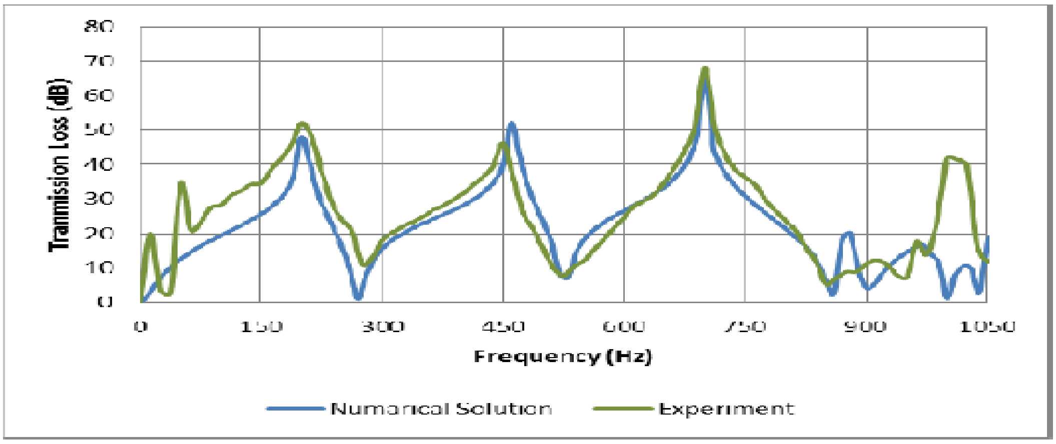

Fig.6: Transmission Loss [9]

c is sound speed and d is the diameter of muffler. Therefore, the frequency axis of the attained graphs was cut at this value. Experimental results show three attenuation picks, which occur approximately between 0-900Hz. These picks are results of the three expansion chambers within the muffler. It can be said that numerical and experimental results are in good agreement. Minor discrepancies between these two results stem from small geometrical differences between the real muffler and CAD model. In Fig. 7 Transmission loss in numerical analysis, total acoustic pressure contours were obtained.

It can be observed that axial resonances and transverse propagation modes are supported by the muffler at this frequency. Total acoustic pressure at 1040 Hz the variation of back pressure with respect to volumetric flow rate is shown in Fig.8

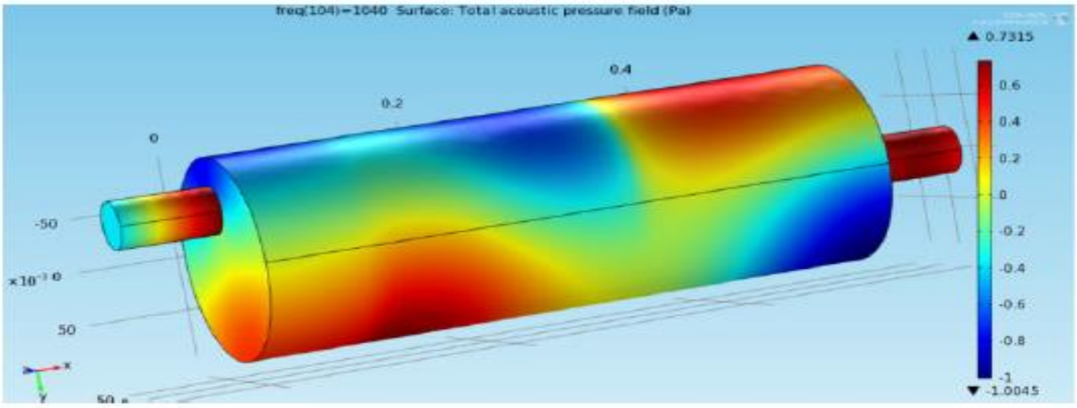

Fig.7: Total acoustic pressure at 1040 Hz [9]

In numerical analysis, total acoustic pressure contours were obtained. In Fig.7 acoustic pressure contours are shown on the cut-off frequency. It can be observed that axial resonances and transverse propagation modes are supported by the muffler at this frequency.

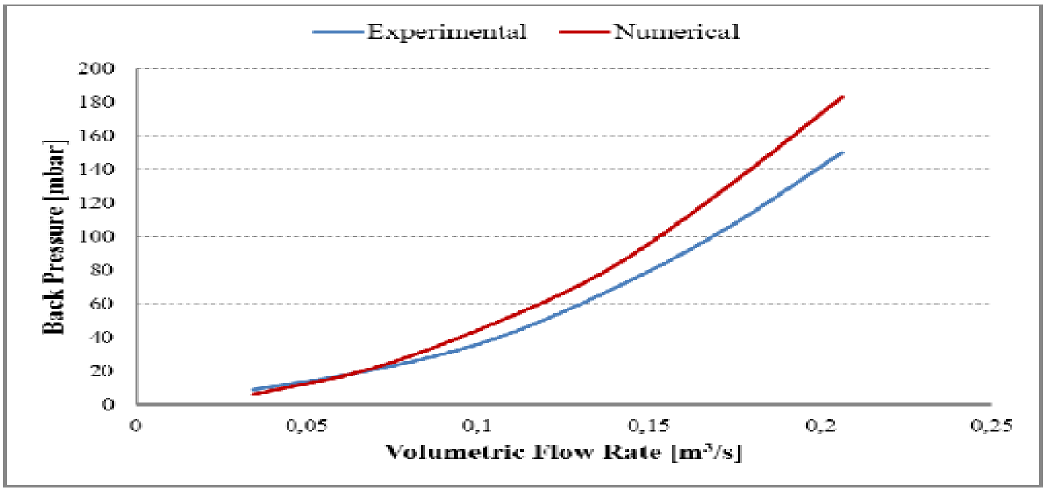

Fig.8. Back pressure values vs. volumetric flow rate [10]

The variation of back pressure with respect to volumetric flow rate is shown in Fig. 8. As shown pressure observed in numerical and experimental data increases with volumetric flow rate. Mean error is approximately 20%. Back pressure which occurred from gasoline engine is required to be maximum at 200 and 300mbar. For the present muffler maximum back pressure is approximately 150mbar and it is acceptable for the engine performance.

VI. CONCLUSION

New regulations and standards for noise emission increasingly compel the automotive improvements about decreasing the engine noise. Considering the cost and the volume of the muffler in the vehicle, the aim is to develop smaller and more compact designs without any loss from the back pressure in muffler. Proposed ne should be analyzed with respect to both acoustics and back pressure. In this study, a reactive perforated muffler is investigated. The present muffler was analyzed to obtain acoustic characteristic. The back pressure affects the engine performance directly an acoustic and flow analysis of the present muffler was examined and compared with experimental results. Transmission loss values obtained from numerical analysis have shown a good agreement with the experimental results. Back pressure values from numerical analysis were calculated with a 20% margin of error. The results of this study will be used as a reference to be able to design new mufflers. So, prior to prototype manufacturing, which is a long and expensive process, different muffler design numerically by examining the effects on acoustic and flow characteristic of the muffler of each parameter, alternative muffler designs will be generated.

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