Acoustic Analysis of a Perforated-pipe Muffler Using ANSYS

***Ezzeddin. M. Milad*[1], *Dr. Mohamed. Jolgaf*[2]**
[1] *The Libyan Academy of Graduate Study*
[2] *Engineering Academy Tajoura, Libya*

Abstract:

In this paper, a three dimensional finite element simulation has been carried out to predict the transmission loss of a simple cylindrical reflective muffler for a given frequency range. Finite element model has been built using ANSYS Workbench 14.5. The result obtained from the simple expansion model were compared with analytical solution and experimental data obtained from previous work by Tao and Seybert. The comparison showed an excellent agreement between finite element, experimental results and analytical solution. To study the effect of adding geometrical features to the design, on the performance of the muffler, a perforated pipe was added to the model to study its effect on transmission loss. The finite element results showed the ability of FEM to represent the *sound attenuation performance of reflective mufflers. This technique can be used with confident to look for other configurations and improve their performance.*

Keywords: *FEA, Optimization, Reflective Muffler, Acoustic Analysis.*

1.Introduction.

Exhaust noise of internal combustion engines is known to be the biggest pollutant of the present day urban environment. Fortunately, however, this noise can be attenuated sufficiently by means of a well-designed muffler [1]. The internal combustion engine released high pressure gases produce high level sound waves. So, attenuating these high sound levels needs an effective muffler. The finite element method (FEM) has proved to be suitable tool to predict the reflective muffler performance with any given geometry. The finite element results of acoustic analysis show good agreement with experiments and analytical results [2-4].

The present work has two objectives. The first objective is to calculate analytically the transmission loss of a simple reflective muffler for a given frequency range. Then using FEM to predict the transmission loss for the same muffler and same frequency range. Then comes the FE model validation, in which the analytical and finite element results are going to be compared to an experimental result obtained from a previous work carried out by Tao and Seybert.

The second objective is to build a three-dimensional finite element model (3D-FEM) for cylindrical expansion chambers with perforated-pipe to study the effect of adding a perforated pipe as new geometrical feature on acoustic attenuation performance.

Analytical solution of simple muffler:

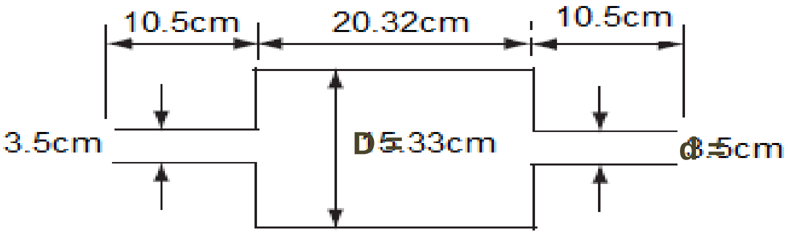

Figure 1: Muffler Dimension

$$\text{Transmission loss (TL)} = 10log_{10}\left[1+\frac{1}{4}\left(m-\frac{1}{m}\right)^2 sin^2 kL_c\right]$$

$$\text{Area ratio } (m) = \frac{\text{Cross sectional area of the expansion chamber}}{\text{Cross sectional area of the inlet circular pipe}}$$

$$\mathrm{m} = \frac{\frac{\pi}{4}\mathrm{D}^2}{\frac{\pi}{4}\mathrm{d}^2} = \frac{\mathrm{D}^2}{\mathrm{d}^2} = \frac{0.153^2}{0.035^2} = 19.26$$

L_c is the length of the chamber

Sound wave number (k) =2πf/c, where **f** is the frequency, and **c** is sonic speed

$k = 2\pi f / 345$

$k_{500\ Hz} = 2(3.14)\ (500)/345 = 9.1061$

$$\mathrm{TL}_{\text{ for 500 Hz}} = 10log_{10}\left[1+\frac{1}{4}\left(19.26-\frac{1}{19.26}\right)^2 sin^2(9.1061*0.2032)\right] = 19.33\mathrm{dB}$$

Then the TL is calculated for the whole frequency range starting from 50 Hz to 3000 Hz with an increment 50 Hz. these results are plotted in Figure 2.

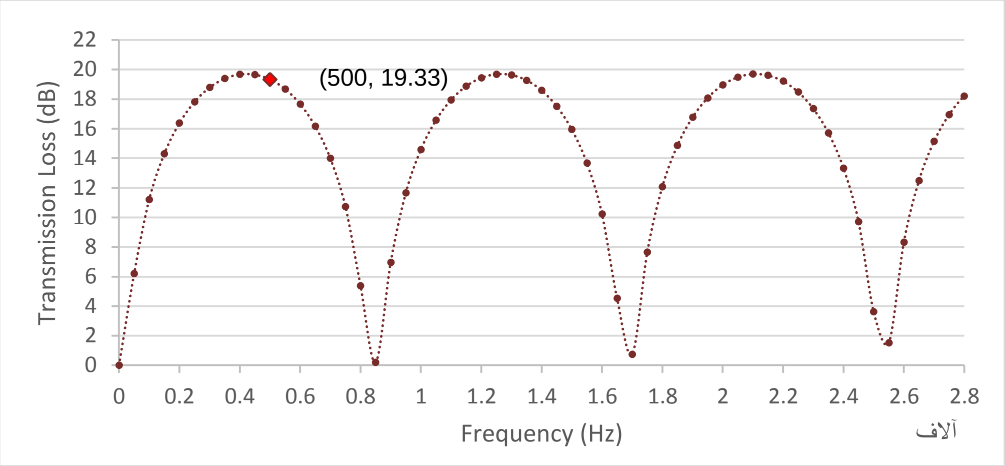

Figure 2: Analytical transmission loss versus frequency for simple muffler

Experimental results of simple muffler:

Experimental results are obtained from the literature of a previous experimental measurements published by Seybert and Tao [5], these results are listed in Table 1. The table contains measured experimental data of the frequency (Hz) and transmission loss (TL).

Table 1: Measured experimental data by Seybert and Tao

Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL
50.0	6.3	450.0	20.2	850.0	0.4	1250.0	20.7	1613.3	11.1	1953.3	19.6	2360.0	19.6	2700.0	11.1
100.0	11.5	**500.0**	**19.8**	900.0	7.8	1300.0	20.4	1646.7	8.3	2000.0	20.9	2406.7	17.4	2726.7	7.2
150.0	14.6	550.0	19.1	950.0	12.6	1350.0	20.2	1666.7	5.2	2060.0	22.0	2453.3	14.8	2760.0	3.5
200.0	16.5	600.0	18.3	1000.0	15.4	1400.0	19.6	1706.7	0.9	2106.7	22.0	2500.0	10.0	2786.7	1.3
250.0	18.0	650.0	16.3	1050.0	17.2	1450.0	18.5	1753.3	7.6	2146.7	22.0	2546.7	1.7	2846.7	0.4
300.0	19.3	700.0	14.3	1100.0	18.5	1500.0	17.0	1800.0	12.4	2200.0	21.7	2580.0	6.3	2893.3	0.7
350.0	19.8	750.0	11.1	1150.0	19.6	1540.0	15.7	1846.7	15.7	2253.3	21.5	2600.0	9.1	2940.0	0.9
400.0	20.4	800.0	5.4	1200.0	20.2	1593.3	12.8	1906.7	18.0	2306.7	20.9	2646.7	13.0	2993.3	1.7

Finite Element Analysis of simple muffler:

The model geometry can be easily created using the design modeller in ANSYS workbench package and then the FEA is carried out using ANSYS solver where various analyses can be conducted. The physical medium that the sound is traveling through is the muffler cavity, which is the air. So, what is going to be modelled, is the muffler cavity (not the steel sheet of the muffler itself) as shown in Figure 3.

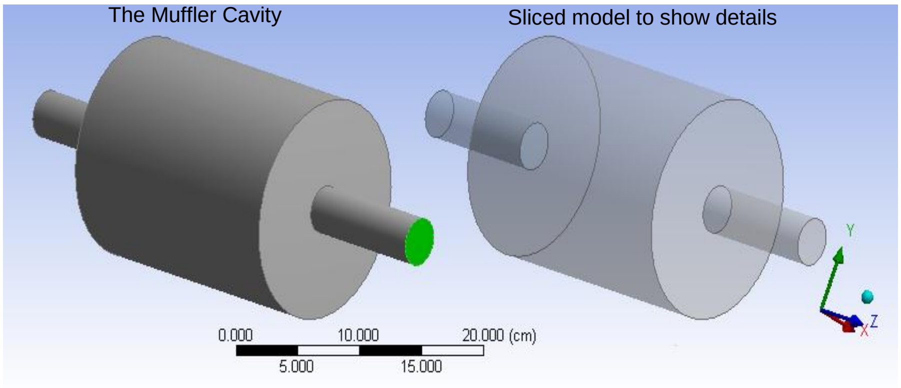

Figure 3: Simple cylindrical reflective muffler.

ANSYS workbench Harmonic Analysis tool box is used to perform transmission loss analysis of the muffler. The model is built and the boundary condition is applied and then the problem is solved to view the results and compare it to the analytical results.

The model is meshed with an element type FLUID221 and uniform mesh size as shown in Figure 4. Mesh size is calculated from smallest wavelength. It is advisable to have at least 6 elements in one wave length[6].

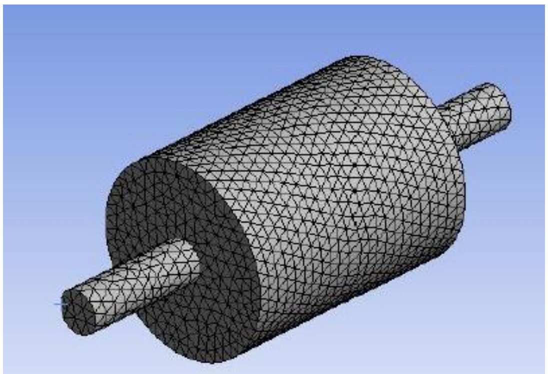

Figure 4: Meshing simple reflective muffler model

Mesh size calculation:

- Max frequency, f= 3000Hz
- Sonic speed in air, C = 343m/s
- Wavelength λ = C/f = 0.1143m
- Element size = λ/6 = 0.019 m In order to get accurate results (LSTC, 2013)
- On safer size, we have used 0.01m.

Analysis settings:

The frequency range 0 to 3000 Hz is going to be divided into intervals to calculate the results. The results can be calculated at every 50Hz by defining solution intervals to 60. For acoustic analysis, only “Full harmonic” solution method can be used.

Loading:

Defining acoustic body:

Acoustic Body can be defined by selecting the model, this will define Mass Density and Sonic speed. In this case, air is used as a medium in muffler.

- Mass Density = 1.2041Kg/m^3
- Sound Speed = 343.24 m/s

Mass Source:

Incident pressure is assumed to be 1Pa. ***Mass source*** boundary condition is used to capture the effect of reflection. If ***Pressure*** boundary condition is selected instead of ***mass source,*** it will not capture the effect of reflection at inlet. If pressure equal to 1pa, the ***mass source*** = 2/Sonic Speed = 0.005826 kg/m^3.s

Radiation Boundary:

“Radiation Boundary” is assigned for both inlet and outlet faces to define anechoic ends at inlet and outlet.

Solver output:

After saving the project, solving can be started to run and execute the analysis. Analysis will be accomplished within 3min depending upon the computer configuration.

Viewing Results:

The finite element simulation results of transmission loss verses Frequency are plotted together with the analytical and experimental results in Figure 5. The plotted FE results show that the maximum attenuation obtained at around 400Hz, 1300Hz and 2150Hz.

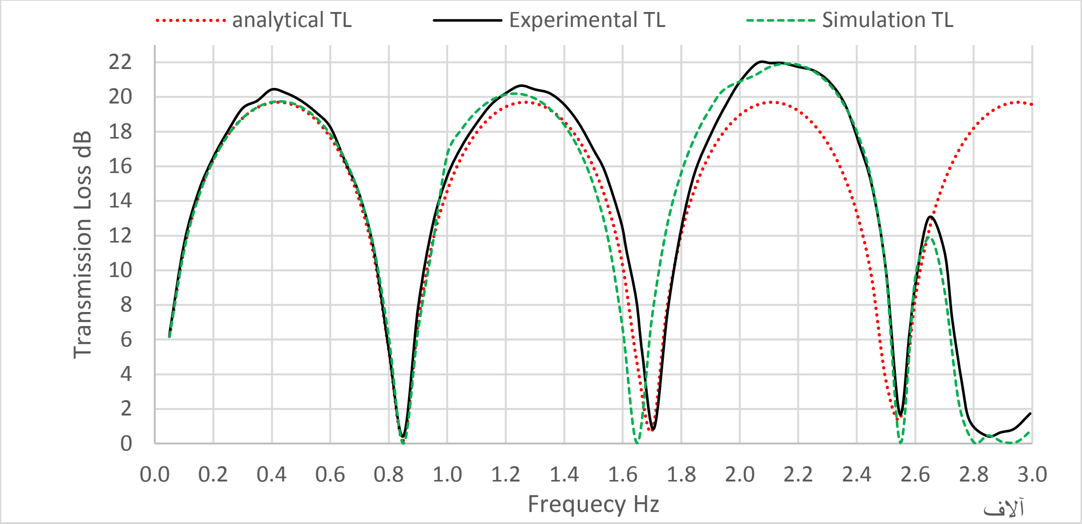

Figure 5: Comparison of FEA with Analytical and Experimental Results.

Figure 5 shows a good agreement of the FEA results with the analytical results at frequencies below 1800 Hz, but the error increases as the frequency increases. The FEA results is in excellent agreement with the experimental results at all frequency range. As a result, the modeling procedure can be confidently used in acoustic analysis of other reflective mufflers geometries.

Finite element analysis of perforated-pipe muffler:

The only difference between the simple muffler and the perforated pipe muffler is the model geometry; the other steps of the modelling procedure are identical.

The pipe is perforated with a hole of 7 mm diameter in the centre of the pipe, then this hole is copied ten times using circular pattern (the result will be 11 holes along the pipe circumference), in addition these holes are copied ten time on both sides using a linear pattern (so that 231 holes are obtained) as shown in Figure 6.

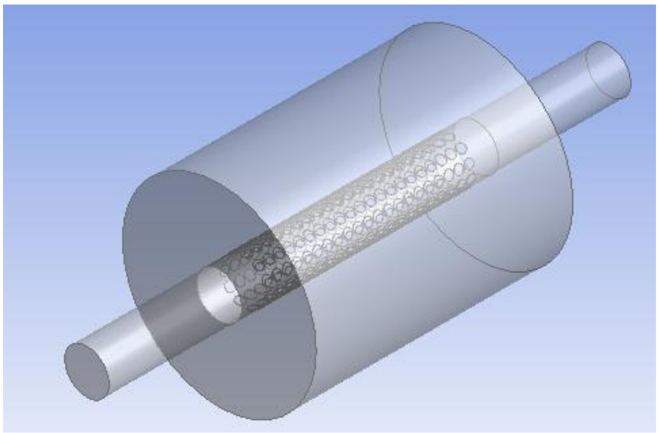

Figure 6: Perforated-Pipe Muffler Modell

Results and Discussion:

By referring Figure 7 shown below, it is found that the transmission loss curve of perforated-pipe muffler is almost identical with the simple muffler at low frequencies (0 to 850 Hz), where there is a slight increase in medium frequencies (900 to 1600 Hz), but it can be noticed that that there is a large increase in transmission loss especially at 2350 Hz where the TL reached the maximum value 61.02 Db. Thus, it is considered the performance of muffler is improving significantly by applying the perforated-pipe especially at high frequencies. These results are in full agreement with what TW Le Roy concluded in his thesis regarding the effect of adding perforated-tube on the transmission loss of muffler at higher frequencies [7].

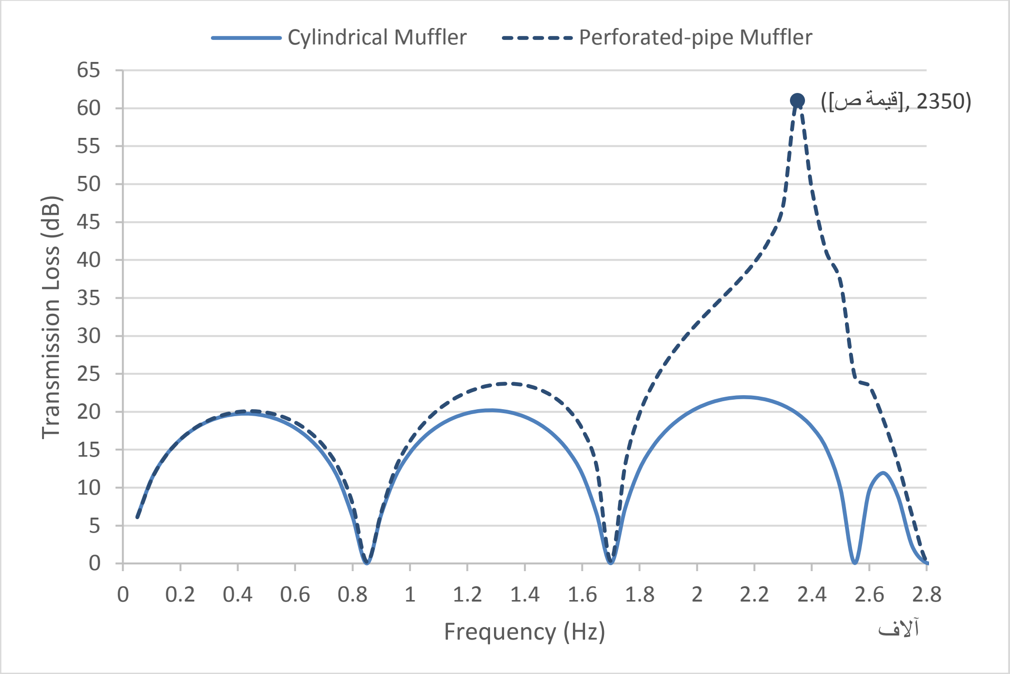

Figure 7: TL curves for the Cylindrical and Perforated-pipe muffler VS Frequency

Transmission loss is the rate of sound pressure level incoming and outgoing from the muffler. Transmission loss is independent from the source and depends on the structure or the geometry of the muffler [8]. Figure 8 shows sound pressure level (SPL) contour distributions for both, the simple cylindrical muffler and for the perforated-pipe muffler at 2350 Hz. The sound pressure levels of the simple cylindrical muffler are 96.97 and 71.2 dB at the inlet and outlet pipe respectively, whereas, they are 96.99 and 29.9 dB in the perforated-pipe muffler.

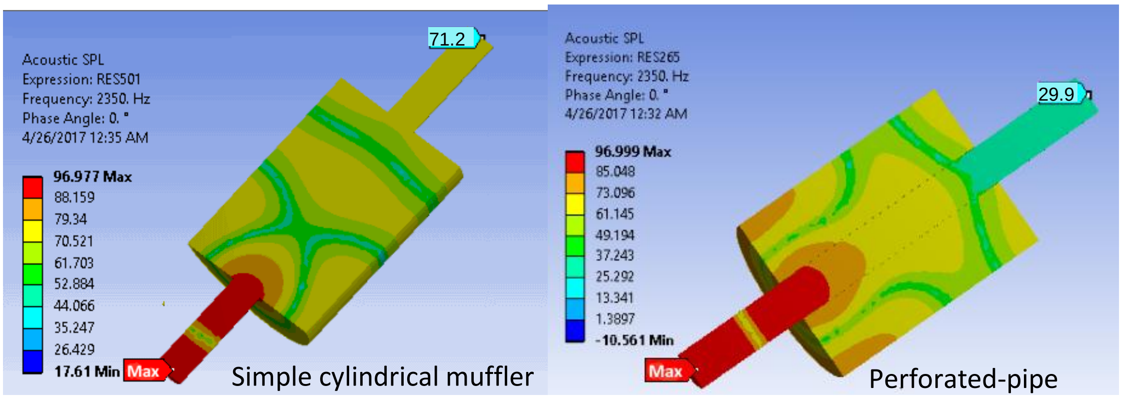

Figure 8: SPL contours distribution at 2350 Hz

Conclusions:

The acoustic simulation analysis on the simple expansion muffler by using ANSYS Harmonic Analysis tool box is carried out successfully. It is found that the simulation for simple expansion muffler gives a very good agreement with both analytical and experimental results. Besides that, simulation results of muffler after applying perforated-pipe on the simple expansion muffler also presented. As a conclusion, adding perforated-pipe improves the transmission loss of cylindrical reflective muffler at higher frequencies, and the simulation model on predicting the transmission loss is considered valid. Further work can be carried out to focus on low frequency range and other muffler geometrical design in addition optimization techniques can be carried out to find out the effect of design parameters on muffler performance.

Acknowledgment:

The authors would like to express their gratitude to the staff members of Engineering Academy Tajoura for their cooperation in various ways during this work.

References:

1. *Munjal, M.L., Acoustics of ducts and mufflers with application to exhaust and ventilation system design. 1987: John Wiley & Sons.*
2. *Mehdizadeh, O.Z. and M. Paraschivoiu, A three-dimensional finite element approach for predicting the transmission loss in mufflers and silencers with no mean flow. Applied Acoustics, 2005.* ***66****(8): p.902-918.*
3. *Selamet, A. and Z. Ji, Acoustic attenuation performance of circular expansion chambers with offset inlet/outlet: I. Analytical approach. Journal of Sound and Vibration, 1998.* ***213****(4): p. 601-617.*
4. *Ma, J.H. and P. Guo. Analysis of performance of automotive exhaust muffler based on ANSYS finite element. in Applied Mechanics and Materials. 2014. Trans Tech Publ.*
5. *Seybert, A.F. and D.F. Ross, Experimental determination of acoustic properties using a two-microphone random-excitation technique. the Journal of the Acoustical Society of America, 1977.* ***61****(5): p. 1362-1370.*
6. *ANSYS, ANSYS Release 14.5 Documentation. 2012, ANSYS, Inc.: Canonsburg, USA.*
7. *Le Roy, T.W., Muffler characterization with implementation of the finite element method and experimental techniques. 2011.*
8. *Parlar, Z., et al. Acoustic and flow field analysis of a perforated muffler design. in Proceedings of World Academy of Science, Engineering and Technology. 2013. World Academy of Science, Engineering and Technology (WASET).*