Experimental Study of Exhaust Muffler System for Direct-Injection Gasoline Engine

Abdallah F. Abd El-Mohsen, Ahmed A. Abdelsamee, Nouby M. Ghazaly

Abstract**—**Engine exhaust noise is considered one of the largest sources of vehicle exterior noise. Further reduction of noise from the vehicle exhaust system will be required, as the vehicle exterior noise regulations become stricter. Therefore, the present study has been carried out to illustrate the role of engine operating parameters and exhaust system construction factors on exhaust noise emitted. The measurements carried out using different exhaust systems, which are mainly used in today's vehicle. The effect of engine speed on the spectra level of exhaust noise is recorded at engine speeds of 900 rpm, 1800 rpm, 2700, rpm 3600 rpm and 4500 rpm. The results indicate that the increase of engine speed causes a significant increase in the spectrum level of exhaust noise. The increase in the number of the outlet of the expansion chamber also reduces the overall level of exhaust noise.

Keywords**—**Exhaust system, engine speed, expansion chamber.

I. Introduction

NOISE pollution has been escalated mainly in the urban areas and presents a danger for the citizen. It has been estimated that 20% of Western European populations are subjected to noise levels, which, experts argue, are unacceptable [1]. The harmful effects and health hazards caused by noise are comparable and even more than the effects of other pollutants such as water and air pollution. The main toxic effect of noise is the loss of hearing ability caused by physiological changes in the inner ear [2]. Noise has been observed to produce high blood pressure, increase heart pulse rate, hardening of arteries and muscular contraction, and headaches and migraines. High noise levels can also cause irritability, insomnia, mental agitation and anxiety. A reduction of overall noise level can only be achieved by lowering the noise level of all its significant noise sources such as, aerodynamic noise, rolling noise (tire noise), transmission and drive line noise, and engine noise [3].

Engine noise could be the major contributor to the overall noise emission, and its noise sources can be classified as, engine structure noise, intake system noise, exhaust system noise, bearing impact noise, valve impact noise, and cooling system noise. Engine exhaust system noise is the highest and contributes much to vehicle noise [4].

Evaluation of cooling water temperature role on petrol engine fuel consumption and noise has been carried out by Moustafa [5]. The outlet temperature of the cooling water of the engine was changed from 30°C to 100°C. He concluded that, the overall level of exhaust noise showed a rise as a result of cooling water temperature increase and the rate of increase was gradually decreased as the cooling water was heated. At high engine speeds, exhaust gas temperature increased as the cooling water temperature was increased and this increase gradually diminished as the cooling water was heated.

Ghosh et al. [6] presented an experimental study to investigate and design a new muffler to controlling the exhaust noise level of a diesel engine and improve the engine performance. The TATA 1210 six-cylinder diesel engine was considered for test purposes. A simulated design, developed by Ricardo with the application of the engine performance simulation program WAVE, was taken up, and this was modified in certain aspects to suit the engine under consideration. Data were taken for speeds of 1000 r/min, 1100 r/min, 1200 r/min, 1300 r/min and 1400 r/min and various loads corresponding to each r/min. They concluded that, the sound pressure level of the TATA 1210 six-cylinder diesel engine recorded with the developed muffler is lower than that with the existing muffler. The exhaust maximum noise reductions recorded with the developed and existing muffler were 19.3 dBA and 14.5 dBA, respectively. The engine brake thermal efficiency is improved up to 4.3%, by using the developed muffler instead of the existing muffler.

Investigations of different exhaust systems and components for a new vehicle with an existing V6 3.2 liter gasoline engine are described by Sartorius [7]. Extensive measurements of exhaust orifice noise for designing the exhaust system are existing. Then the sensitivity of main parameters such as exhaust system configuration (one or two rear muffler systems), volume of rear mufflers, several mid muffler concepts and tail pipe diameter on the pass-by noise target value and engine performance is considered. The results indicated that, the overall sound pressure level of the baseline system with two rear mufflers is up to 1800 rpm below the target value and above 1800 rpm the level is about 5 dBA to high. The mid muffler with one chamber (the volume is built around the crossover of the baseline system) damps little bit better than the mid muffler with three chambers. Increasing rear muffler volume decreases the overall sound pressure level over the whole engine speed range. Reducing the tailpipe diameter also reduces the overall sound pressure level over the whole engine speed range.

The noise emitted by the exhaust system is influenced by various components of the system and by the operating parameters of the engine. Therefore, the object of the study described in this paper is to investigate the role of exhaust system constructional parameters, as well as, engine operating

Abdallah F. Abd El-Mohsen, Ahmed A. Abdelsamee and Nouby M. Ghazaly are with the Mechanical Engineering Department Faculty of Engineering, South Valley University, Qena-83521, Egypt (corresponding author; e-mail: nouby.ghazaly@eng.svu.edu.eg).

parameters on the spectra and the overall noise level emitted by the petrol engine exhaust system. The influence of tailpipe number, exit angle, and vibration, as well as, exhaust pipe length and diameter is studied.

II. Test Rige and Instrumentation Systems

The main objective of the present test equipment is the ability to measure engine exhaust noise levels and exhaust gas temperature to evaluate the influence of engine operating parameters as well as the influence of silencer construction parameters on these levels. The experimental work is carried out using in-line, water-cooling four- stroke, injector gasoline engine. The engine has the following specification; four-cylinder, capacity 1998 cc, bore/stroke 86/86 mm. Compression ratio 9, maximum power 131 hp at 5400 rpm and, each cylinder provided with two valves. The exhaust gas is escaped to atmosphere through exhaust system consists of exhaust manifold, straight pipe of 440 cm length and 50.8 mm diameter, expansion chamber, resonator chamber and tailpipe. Engine auxiliary equipment and engine cooling system located on the front of the engine. The engine was mounted on a test bed provided with hydraulic brake system as shown in Fig. 1. The exhaust outlet open pipe is straight and the height of its flow axis above the ground is 0.25 meter. The microphone of the sound level meter is located at a distance of one meter from the exhaust pipe outlet with its axis has an angle of 45 degree to the flow axis where microphone sensitivity is maximum and at the same height as the axis of the gases flow.

The emitted noise spectra were recorded in terms of third octave frequency bands, and are expressed in the used sound pressure level units, that dB relative to $2 * 10^{-5}$ N/m^{-2}. The overall noise level ware obtained in dBA since the present international standards for noise measurements and evaluation in general recommend the use of A- frequently "A-frequently weighting scale gives an approximate indication of noise level as it affects the human ear". Before testing, the sound level meter had been calibrated using sound level meter calibrator, which is accurate to be 0.5 dB.

The exhaust gases after having passed out of exhaust valve find their way out to exhaust silencer via exhaust manifold and exhaust pipe. The silencer reduces the temperature of exhaust gases, damps down its sound, and controls the backpressure of the engine. From the acoustic point of view, the silencer is a broadband filter with a maximum attenuation required in the range 100-500 Hz, the nosiest part of the exhaust spectrum [8].

The construction of the expansion chambers which have been used in this study are shown in Fig. 2, which depicts a schematic diagram of expansion chamber (A), which has 50 cm long, 15 cm diameter, and 2 mm wall thickness. The perforated tube in the center of the expansion chamber is 50.8 mm diameter and the round holes are 3 mm diameter. The tube is designed to have comparable distance between holes in both axial and circumferential directions. It is divided into two equal volumes separated by baffle plate. The exhaust gases pass from one chamber to another through tube has 40 mm diameter. The length of the chamber is 48 cm, the inner diameter is 14.5 cm, and, the wall thickness is 2 mm.

Fig. 1 Photo of the engine mounted on the test bench

Fig. 2 Construction of the expansion chambers

III. Experimental Results and Discussion

A. Effect of Engine Speed

The effect of engine speed on the spectra level of exhaust noise is recorded at engine speeds of 900, 1800, 2700, 3600 and 4500 rpm. From Figs. 3-5, the experimental results show that the increase of engine speed causes an increase in spectra levels of exhaust noise. With the exhaust system which has no expansion chamber, the increase of engine speed from 900 rpm to 4500 rpm produces an increase of about 22 dB in the spectra levels at frequency of 1000 Hz. With the exhaust system which has one expansion chamber the increase of engine speed from 900 rpm to 4500 rpm produces an increase of about 19 dB in the spectra levels at frequency of 1000 Hz. Also with the actual exhaust system used in the vehicle, which contains primary and secondary expansion chambers, the increase of engine speed from 900 rpm to 4500 rpm produces an increase of about 19 dB in the spectra levels at frequency of 1000 Hz. The spectra shapes remain approximately the same through the frequency range from about 10 Hz to 2 kHz, and have high levels at frequency range from about 60 Hz to about 200 Hz where the first and second harmonics are predominant when the engine is operating at speed range from 900 rpm to 4500 rpm.

Exhaust noise is a mixture of multi-tonal noise generated by the valve events and resonance in the pipe superimposed on broad band noise generated by the gas flow. As one cylinder after another discharge into the manifold, there must perforce be pressure fluctuation in the latter. Pressure variations in the manifold, however are influences also by wave formation and reflection. It is also found to increase markedly with engine speed and load, which are affected considerably by design variables. The lower frequency part of the spectrum appears to be due to a resonance effect between the varying capacities of the cylinder and exhaust system as the piston moves in the exhaust stroke and the area through the valve as it opens and closes. The high frequency part of the spectrum is due primarily to the release of high pressure gas through the exhaust ports. Therefore, exhaust noise is a function of valve timing, valve clearance, camshaft design, manifold geometry, engine speed, engine load and many other parameters. The present results are in a good agreement with the result obtained by [9], which indicated that, engine exhaust noise is greatly affected by both of engine speed and engine load. Also, it is in general agreement with the results obtained in [10].

B. Influence of Double Chamber

The influence of expansion chamber with single inlet and double outlet on the spectra and the overall level of exhaust noise have been investigated. The same inlet and outlet diameter, and dimensions expansion chambers have been used. The results were recorded at 900 rpm, 1800 rpm, 2700 rpm, 3600 rpm and 4500 rpm engine speed and at no load, and at 3 hp, 6 hp, 9 hp and 12 hp engine load and at 2500 rpm engine speed. Figs. 6-8 illustrate this influence as follows: From the results it can be seen that, the overall level of exhaust noise has been decreased by about 4.4 dBA with double outlet at low engine speed and by about 1 dBA at high engine speed. Also, the overall level of exhaust noise has been decreased by about 2.5 dBA with double outlet at 5 hp engine load and by 1.5 dBA at 30 hp engine load. The spectra levels of exhaust noise emitted decreased through the frequency range from 20 Hz to 800 Hz, while, in the frequency range from 800 Hz to 4 kHz remain almost the same. These results are in agreement with the result obtained by [10] which stated that, the expansion chamber, which provided with double outlet, produces a decrease in the mean velocity of the exhaust gases, while keeping the same diameter, so that the radiation noise is not necessarily increased. The only point to consider is that, since a single source has been replaced by two sources, both the flow field in the discharge region and the radiation field at a certain distance may be modified. These eventual modifications must, in principle, depend on the relative position of the two tailpipes, but also on any eventual differences between the noise radiated by each of the tailpipes.

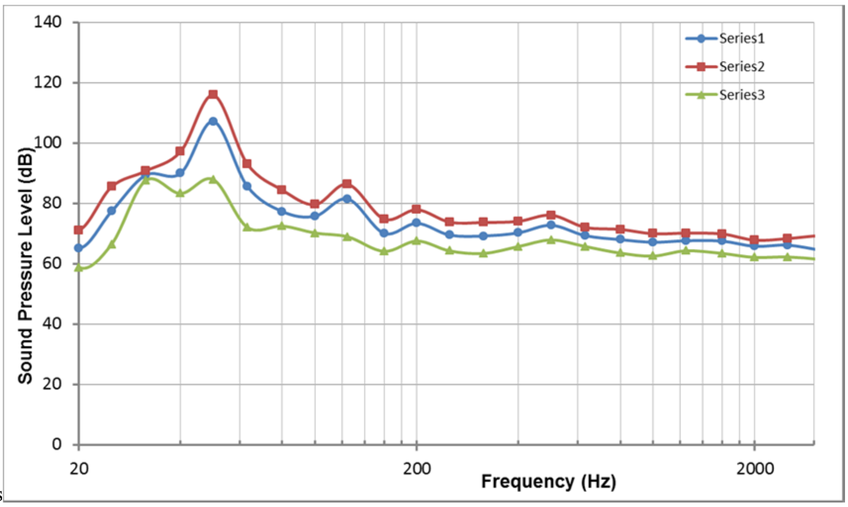

Fig. 3 Effect of speed on the spectra with equivalent straight pipe at no load

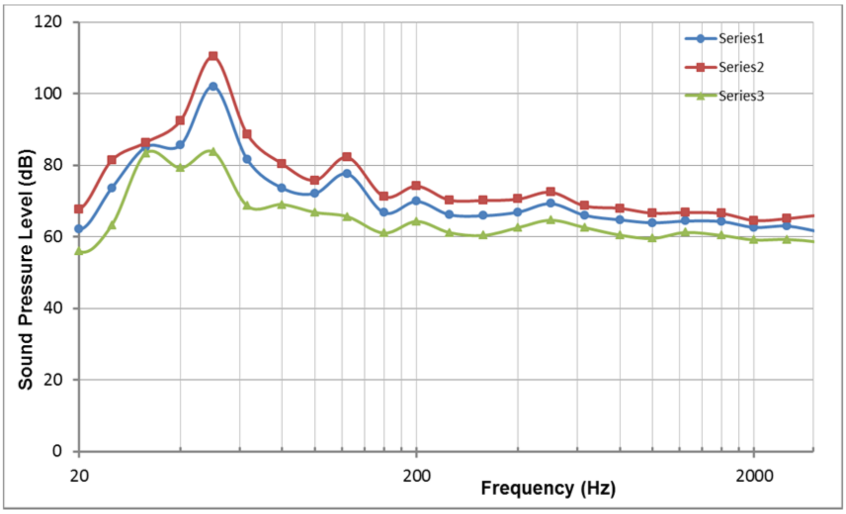

Fig. 4 Effect of speed on the spectra with one expansion chamber at no load

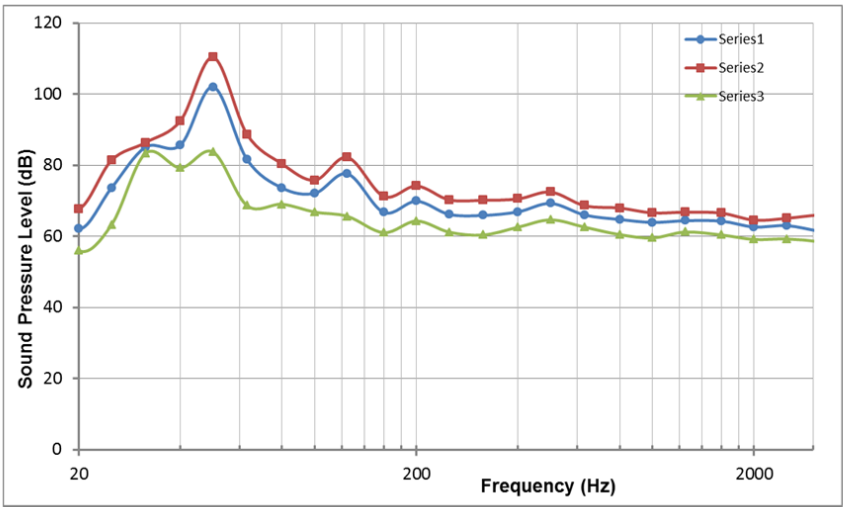

Fig. 5 Effect of speed on the spectra with two expansion chamber at no load

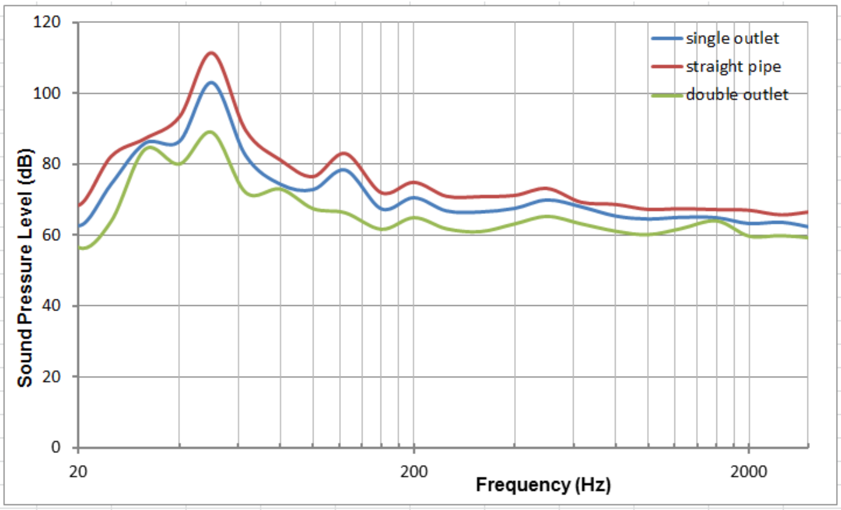

Fig. 6 Effect of double outlet muffler on exhaust noise spectra at 900 rpm

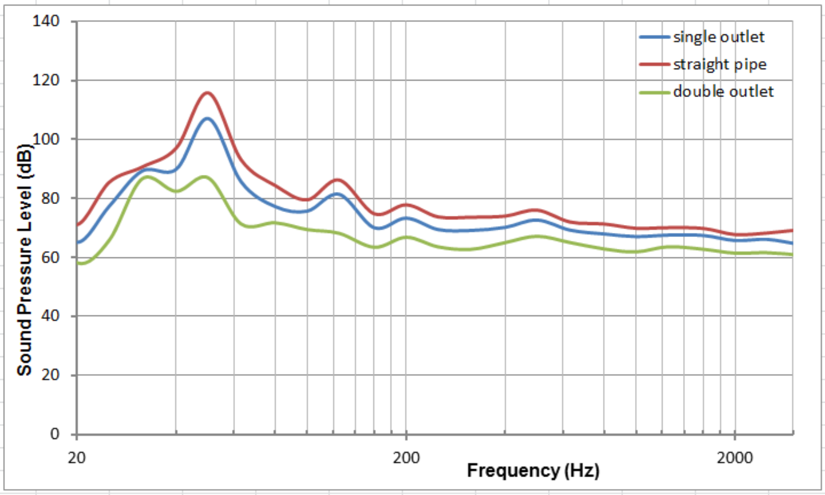

Fig. 7 Effect of double outlet muffler on exhaust noise spectra at 1800 rpm

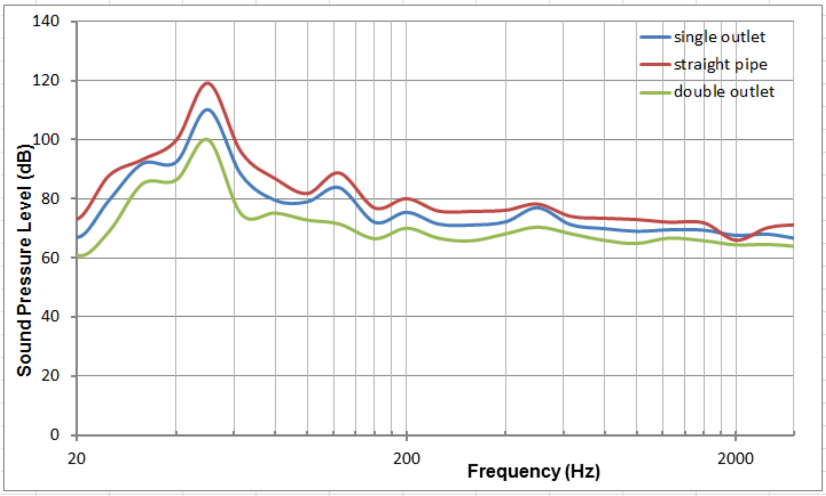

Fig. 8 Effect of double outlet muffler on exhaust noise spectra at 2700 rpm

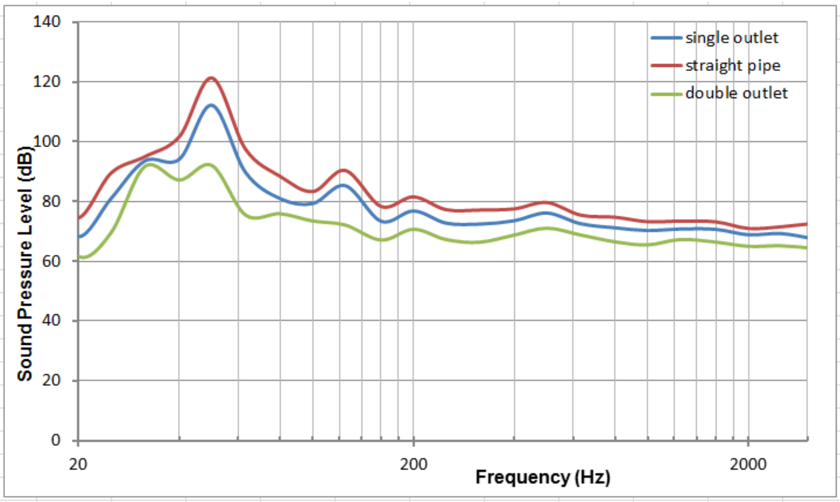

Fig. 9 Effect of double outlet muffler on exhaust noise spectra at 3600 rpm

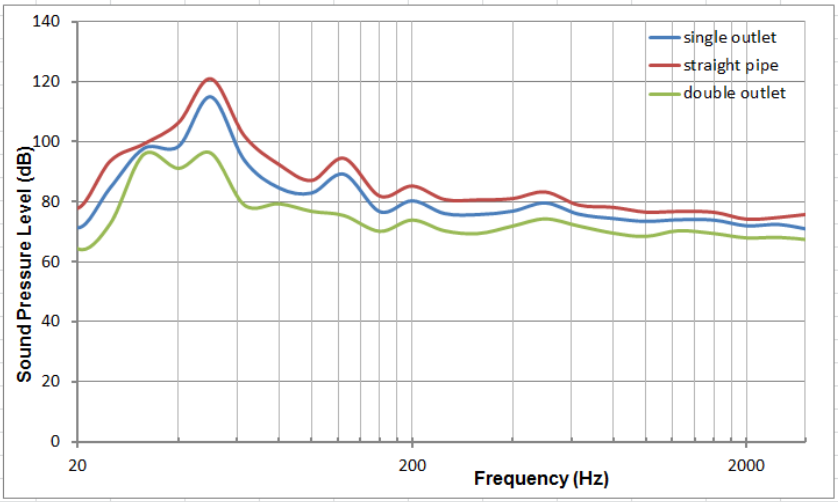

Fig. 10 Effect of double outlet muffler on exhaust noise spectra at 4500 rpm

IV. Conclusions

This paper presents experimental tests which are carried out on exhaust system test rig under different speeds and loads. The effect of variation in build-up parameters on noise reduction in automobile engine muffler has been investigated. Based on the results from the experimental work, it is found that engine speed has significant influence on engine exhaust noise, the levels of spectra noise increase as a result of its increase. In additions, expansion chamber, which has double outlet, causes a decrease in the overall level of exhaust noise as well as the spectra levels.

References

[1] M. S. Howe, The Damping of Sound by wall Turbulent Sheer Layers, 1995 Journal of the Acoustical Society of America 98(3), 1723-1730.
[2] P. O. A. L. Davies and HOLLAND, the Measurement of Sound Power Flux in Flow Ducts 2000, 230(4), 915-932.
[3] M.ÅBOM, Measurement of the Scattering-Matrix of Acoustical Two-Ports, 1991 Journal of Mech. System and Signal Processing 5(2), 89-104.
[4] L. J. Eriksson, Higher order mode effects in circular ducts and expansion chambers, 1980 Journal of the Acoustical Society of America 68, 545-550
[5] AVL BOOST-SID, Linear Acoustics, user Manual.
[6] P. O. A. L. Davies et al, Reflection Coefficients for an unflanged pipe with flow, 1980 Journal of Sound and Vibration 72, 543-546.
[7] J. G. Ih & B.H. Lee, Analysis of Higher order modes effects in the circular expansion chamber with mean flow.1985 Journal of the Acoustical Society of America 77(4) 1377-1388.
[8] Wagh, S., Sen, S., Iyer, G. and Shukla, S. "Development of Exhaust Silencer for Improved Sound quality and Optimum Back Pressure". SAE technical papers, 2010- 01-0388, Detroit, MI, 2018.
[9] M.ÅBOM, Derivation of Four-pole Parameters including higher order mode effects for expansion chamber mufflers with extended inlet and outlet, 1990 Journal of Sound and Vibration 137(3), 403-418.
[10] Meisner G.P. "Advanced Thermoelectric Materials and Generator Technology for Automotive Waste Heat at GM". Thermoelectric Applications Workshop, USA, 2017.