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INVESTIGATION THE EFFECT OF THE REACTIVE MUFFLER CONNECTIONS ON NOISE ATTENUATION

دراسة تأثير طرق الربط لكاتم الصوت التفاعلي على تخفيض الضوضاء

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ABSTRACT

A pollutant of concern to the mankind is the exhaust noise in the internal combustion engine. However this noise can be reduced sufficiently by means of a well designed muffler. The suitable design and development will help to reduce the noise level.

The author design and fabricate a reactive muffler, spherical and cylinder shapes, afterward compared the noise level for these shapes with parallel and series connections. Transmission loss and transmission coefficient are calculated experimentally and theoretically for one, double and three mufflers in parallel and in series. Exhaust noise levels will aid the manufacturer in determining the correct muffler to meet the required noise reduction. These mufflers tested in frequency ranging between (50-600) Hz. In this study, the rustles show that the parallel connection is best than the series connection.

Keywords: Muffler Connection, Noise Reduction.

الخلاصـــــة

تزايد الاهتمام بضوضاء العادم في محرك الاحتراق الداخلي حيث ان هذه الضوضاء يمكن ان تقلل بما فيه الكفاية بواسطة كاتم الصوت لان التصميم المناسب وتطويره يساعدان على تقليل مستوى هذه الضوضاء. في هذه الدراسة تم تصميم وتصنيع كاتم تفاعلي كروي واسطواني الشكل حيث تم مقارنة مستوى الضوضاء لهذه الاشكال بربط التوازي والتوالي. خسارة الارسال (TL) ومعامل الارسال (TC) محسوبان بشكل تجريبي ونظري لكاتم واحد وثنائي وثلاثة كواتم بالتوالي والتوازي . مستويات ضوضاء العادم ستساعد في تقرير الكاتم الصحيح، هذه االكواتم اختبرت في تردد يتراوح ما بين (50-600) هيرتز . في هذه الدراسة اثبتت النتائج ان ربط التوازي للكاتم افضل من ربط التوالي.

NOMENCLATURE

A	Area, m^2
C	Sound speed ,m/s
D	Diameter of expansion chamber
k	Number of waves
$\mathbf{P_i}$	Incident pressure
P_r	Reflected wave pressure
s	Cross section area

1-INTRODUCTION

In an automobile, the exhaust system carries exhaust gases from the engine's combustion chamber to the atmosphere. Exhaust noise of internal combustion engines iron mentis known to be the biggest pollutant of the present-day urban environment. Fortunately, however, this noise can be reduced sufficiently by means of a well-designed muffler which is also known as silence. Nowadays, the silencers are made with different shapes, volumes and very complex internal sections. As a consequence of the constructive complexity, there is a region inside it where the one-dimensional theory cannot be applied. This occurs due to the appearance of multi-dimensional waves with the simultaneous propagation of waves in the axial and radial directions when the excitation reaches the frequency range where the wavelength is smaller than the largest dimension of the cross-section of the silencer. Such effect causes a considerable difference between the plane wave theory results and the experimental results (**Munjal et al., 1987).**

Muna, et. al., 2012, found that the tailpipe acts as a resonant cavity that couples with the muffler cavity. In order to minimize the noise level, different pipe lengths of inlet and outlet (discharge) tubes are studied with a specific diameter. The conclusion was that the taller outlet pipe the higher noise attenuation. Orifice plates are most commonly used as primary element for flow measurement in pipe line based on the principle of measurement of differential pressure created when an obstruction is placed in the fluid flow due to increase in fluid velocity. Orifice plate cover a wide range of applications of fluid and operating conditions they give an acceptable level of uncertainties at lowest cost and long life without require maintenance. The orifice plates are correctly finished to the dimensions, surface roughness and flatness to the applicable standard these plates are recommended for clean liquid, gasses & steam flow. The orifice plate bore can be made in many configurations to handle various flow measurement jobs.

Lenzi and Barbieri, 2011, studied the application of shape and parametric optimization techniques in the study of reactive silencers with extended inlet and outlet ducts. Parametric optimization is employed to evaluate the appropriate size of the inlet and outlet ducts. Shape optimization is employed to establish the proper profile of these ducts in order to improve the acoustic features of these mufflers in a specific frequency range. The objective function used in the optimization processes is defined through the average transmission loss (TL) for the desired frequency range. This type of objective function is strongly non-linear and the genetic algorithm, GA, was chosen as a mathematical method for determining the maximum of this function. The Finite Element Method with an axisymmetric formulation along with the modified four-parameter method are used to calculate the TL. The Hermit polynomials were used in the shape optimization in order to obtain local boundary approximations with C1 continuity. The results showed the optimization efficiency of the inlet ducts profile for acting in specific frequency ranges with gains up to 20dB with respect to silencers without shape optimization. The numerical analyses agree well with experimental results.

Muthana et. Al, 2011, built a test rig for a reactive muffler. Different orifice shapes are used with the same bore area to study the effect of the orifice shape on noise reduction. Also the effect of the number of orifices in one plate and multi plate orifice is discussed. It has been found that the multi plate circle orifice and triangle orifice give the most suitable results.

Shape optimization of multi-chamber mufflers with plug-inlet tube on a venting process by genetic algorithms were investigated by (**Min-Chie Chiu, 2010)**. A numerical case for eliminating broadband steam blow-off noise using multi-chamber plug-inlet mufflers in conjunction with a genetic algorithm (GA) as well as a numerical decoupling technique, all within a space-constrained pressure drop. To verify the reliability of the GA optimization, optimal noise abatements for various pure tones on a one-chamber plug-inlet muffler are examined. Of course, the accuracy of the mathematical model must be supported by experimental data. Subsequently, optimal results then indicate that the maximal sound transmission losses are indeed located at the desired target tones. Consequently, both pressure drop and acoustical performance will increase when the diameters (at inlet tubes and perforated holes), the perforated ratio, and the length of perforated tubes are decreased.

Zhaorong, 2009, studied the internal laws of silencers' acoustic attenuation performance, when the cross-sectional shape, length and diameter of the expansion chamber changed. Based on the BEM-FEM coupled model and to combine with the improved Four-pole Parameters Method, the transmission loss (TL) was calculated. It is pointed that the flatter the expansion chamber is, the worse the performance is. When the length decreases, the domes of the TL become broader, and the number of domes decreases. When the diameter increases, the TL increases, but the growth rate and the inactive frequency decrease. The results indicate that by using computer modeling analysis, it is sensible to optimize the shape to meet the needs of the eliminating frequency band and the applied circumstance. In all muffler designs the tailpipe length can have an important effect.

Rahman, et. al., 2005, investigated the most effective means of reducing noise by changing the design of muffler. But, muffler requires specific design and construction considering various noise parameters produced by the engine. The conventional design does not include much of a parametric noise analysis or other engine characteristics. A muffler for stationary petrol engine has been designed and manufactured. The performance characteristics, i.e. noise reduction capability of the muffler, has been tested and compared with that of the conventional muffler. The result has been found to be quite satisfactory.

In this paper, the reactive silencers with two shapes (spherical and cylindrical) are used with connection parallel and series one, two, and three silences to detect the effect of the shape on noise attenuation in the muffler.

2. THEORETICAL CONSIDRATION

The active silencer is capable to reduce the exhaust noise from 91 dB to 78 dB after the tail pipe outlet, with a back pressure of 3 kPa to the engine.

The quantity most often used to measure the "strength" of a sound wave is the **sound pressure level** (*Lp* or SPL) measured with respect to a standard reference pressure of $p_{ref} = 2 \times 10^{-5}$ Pa.

The sound pressure level can be calculated using the following formula (**Beranek and Ver, 1992**):

$$SPL=20\ \log_{10}(P/P_{ref})(dB) \tag{1}$$

There are several parameters to describe the acoustic attenuation performance of an expansion chamber. These include the Noise Reduction (NR), the Insertion Loss (IL) and the Transmission Loss (TL). Among these acoustic parameters, the TL is the only one that can be easily calculated and measured according to the main aim of this paper. It is defined as the difference in the sound power level between the incident wave exciting the mufflers W_i and the transmitted wave W_t to an anechoic termination.

$$TL=10\log_{10}(W_i/W_t) \tag{2}$$

$$TL = 10\log_{10}\left[1 + 0.25 * \left(m - \frac{1}{m}\right)^2 \sin^2 kl\right] \tag{3}$$

$$k = w/c$$

$$w = 2\pi f$$

$$m = \frac{D^2}{d^2}$$

Where:
(w): angular velocity
D = Diameter of the expansion chamber (15.3 cm)
d=Diameter of the inlet pipe (4.7cm)
(k) = No. of waves
(L)= Length of expansion chamber (24cm)
(c)= Sound speed (343m/sec)

The Transmission Coefficient in the silencer can be calculated from the following (**Harris, 1979**)

$$Tc = \frac{4}{[4\cos^2 kl + (m + \frac{1}{m})^2 \sin^2 kl]} \tag{4}$$

The experimental results contain the calculation to find the values of transmission losses **(TL)** which equal the difference between sound pressure level at inlet and outlet**,** and find transmission coefficient **(TC).**

3. EXPERIMENTAL WORK

Test parts arrangement shown in **figure (1)**.
Two mufflers with two shapes spherical and cylindrical were fabricated as test section. The spherical muffler was formed carefully from copper sheet with diameter 21cm as shown in **figure (2).**
But the cylindrical muffler were formed a galvanized steel sheet pipe having a diameter of 21 cm and 25cm length as shown in **figure (3).**
The inside of silencer is empty because this study is concerned with the effect of shape of silencer on noise reduction. The diameter of the inlet pipe is taken same as the diameter of the exhaust of the silencer and equal is (5 cm) for both design.

The signal generator is connected to the amplifier which is connected to the loudspeaker. The loudspeaker is isolated in the box to prevent sound reflection and also to prevent any external disturbance. The other end of the box is connected to the cone which is joined to the SPL meter.

The signal generator is turned on to give assign with frequency from (50 to 600) Hz step 50Hz, a, and select sinusoidal wave. The SPL meter readings are recorded, then the test muffler is placed at the con end and the SPL meter is placed at the mufflers other end.

The test rig is made from the following components:
1-signal generator: to generate sound signal with different frequency and operate (0HZ to more than 1000HZ).
2- Amplifier.
3-loudspeaker: 8 inch size
4- A Box: to cover the loudspeaker, insulated from inside to prevent sound reflection.
5- A Cone-shape connector: attached to the box to force the sound wave pass in one path.
6- Pipes: to connect the experiments parts (the signal generator, loud speaker, box and cone)
7- Reactive muffler with different connection.
8- Sound pressure level meter: The sound level meter is the most common instrument used in measuring noise sources. A sound level meter works by using a microphone to sense sound pressure, and electronic circuitry to convert the sound pressure to an SPL reading.

The test parts of the experimental apparatus are shown in f**igure (4).** The following procedure steps were conducted for each experimental session after completing checking for the system:

1- Test one, two, and three spherical silencer in series connection is shown in **figure (5a)**.
2- Test one, two, and three spherical silencer in parallel connection is shown in **figure (5b)**.

3- Test one, two, and three cylindrical silencer in series connection **figure (6a)**.

4- Test one, two, and three cylindrical Silencer in parallel connection **figure (6b)**.

Repeat the experimental procedure for every case, by changing frequency from 50 to 600 Hz step 50 Hz.

4- RESULTS AND DISCUSSION

For every case, the values of TL and TC are analyzed graphically due to the frequency. The experimental results are the recorded values of transmission losses (TL) and to find values of transmission coefficient (Tc). The values of TL and TC are analyzed graphically due to the frequency. As shown from the figures, in most cases, there is no differences between the values of TL and TC at low frequencies(50-200) Hz because the effect of noise for reactive muffler is obvious at frequencies more than theses values. **Figures (7** and **8)** represent results for spherical silencers in series connection for the one, two, and three. The results show that the transmission losses (TL) for two silencers connection in series are better during the all range of frequency comparison with the one and three silencers.
In the TL curve can be noticed the TL peaks at the frequency (350 Hz) .

Figures (9 and **10)** represent Transmission Losses and Transmission Coefficient for spherical silencer parallel connection. The result show that the three silencers in parallel connection have been dramatically reduced the noise. It is interesting to note that the acoustical performance of the three silencers in parallel connection is better than the two silencers under a same frequency range. In the TL curve can be noticed the TL peaks at the high frequency (350 Hz).

The values of TL and TC are analyzed graphically due to the frequency. **Figures (11**and **12)** represent results for cylindrical silencers in series connection for the one, two, and three. Also the results show that the transmission losses (TL) for two silencers connection in series are better during the all range of frequency comparison with the one and three silencers.
In the TL curve can be noticed the TL peaks happened at the frequency range between (500-600) Hz.

Figures (13and**14)** are show Transmission Losses and Transmission Coefficient for cylindrical silencer parallel connection. The result also shows that the three silencers in parallel connection are better than the two and one silencers under a same frequency range. In the TL curve can be noticed the TL peaks happened at the frequency range between (200-400) Hz.
The values of TL and TC are calculated by using equs. **(3and4)** for cylindrical muffler, where **Figures (15** and **16)** represent theoretical results for cylindrical silencers in series connection for the one, two, and three. **Figures (17** and **18)** show theoretical results for spherical silencer. Also theoretical results show that the transmission losses (TL) for silencers connection in parallel are better during the all range of frequency comparison with the series silencer connections.
In the TL curve can be noticed the TL peaks happened at the frequency range between (300-350) Hz.
All the rustles show that the parallel connection is best than the series connection.

5- CONCLUSIONS

This paper shows that the parametric optimization along with connection optimization produces well result in the reactive silencers optimization. The study has the following conclusions:

- Two silencers connection in series is better than one and three silencers.
- In spherical silencers the TL peaks were happened at the frequency(350) Hz.
- Three silencers in parallel connection are better than the two and one silencer.
- In cylindrical silencers the TL is greater than spherical silencer for the same connections.

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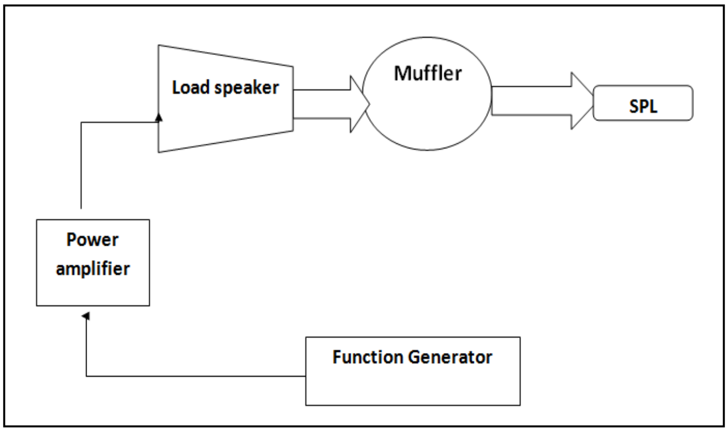


Figure (1): Schematic diagram of test rig arrangement.

Figure (2a): Photo of spherical silencer

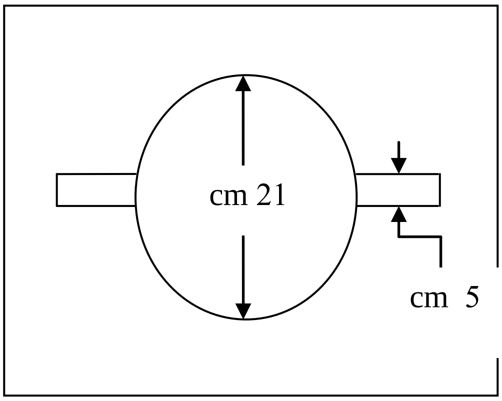


Figure (2b): Inside of spherical silencer

Figure (3a): Photo of cylindrical silencer

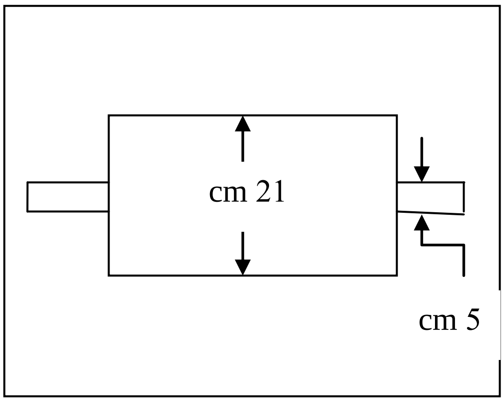


Figure (3b): Inside of cylindrical silencer

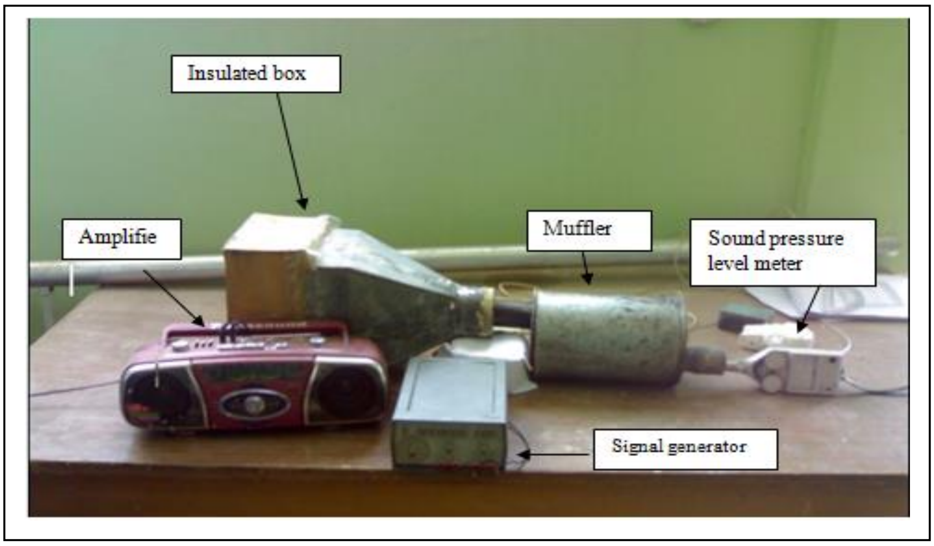
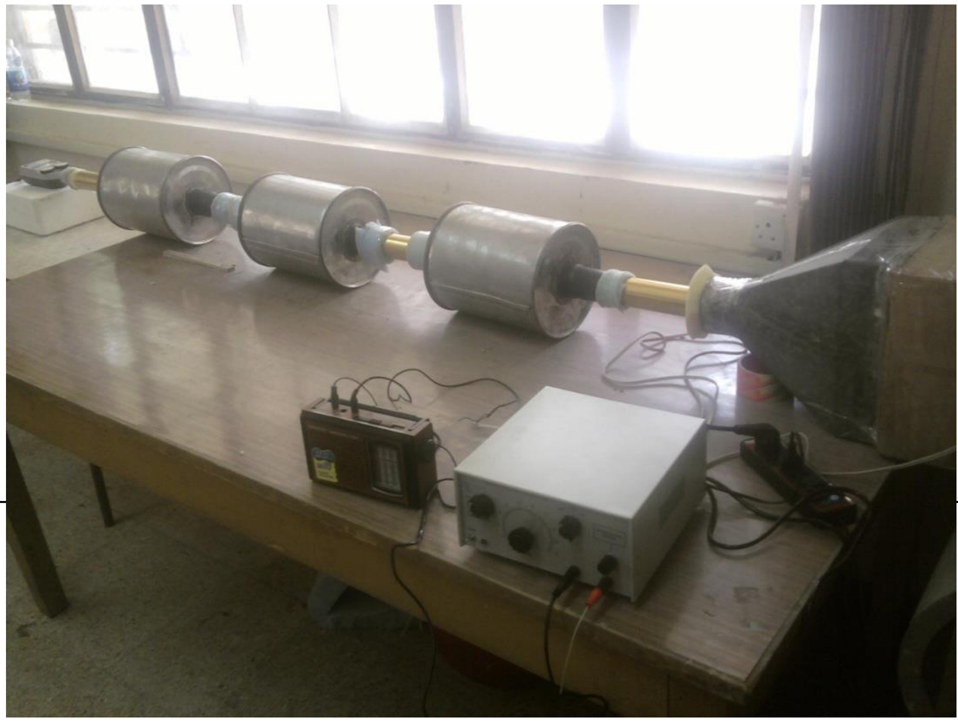
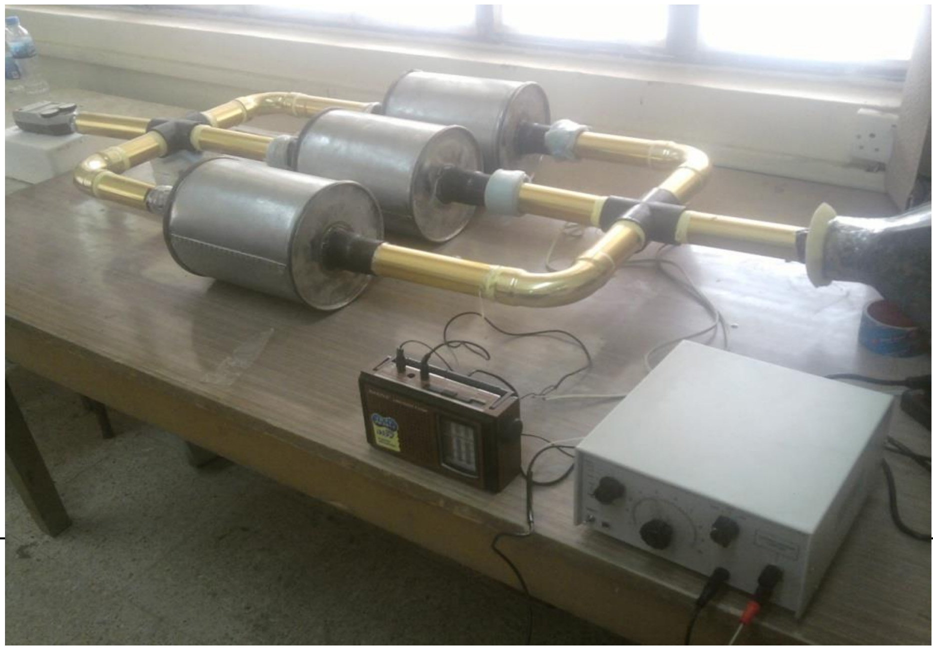


Figure (4): Photo of the test parts.

Figure (5a): Photo of spherical silencers in series connection.

Figure (5b): Photo of spherical silencers in parallel connection.





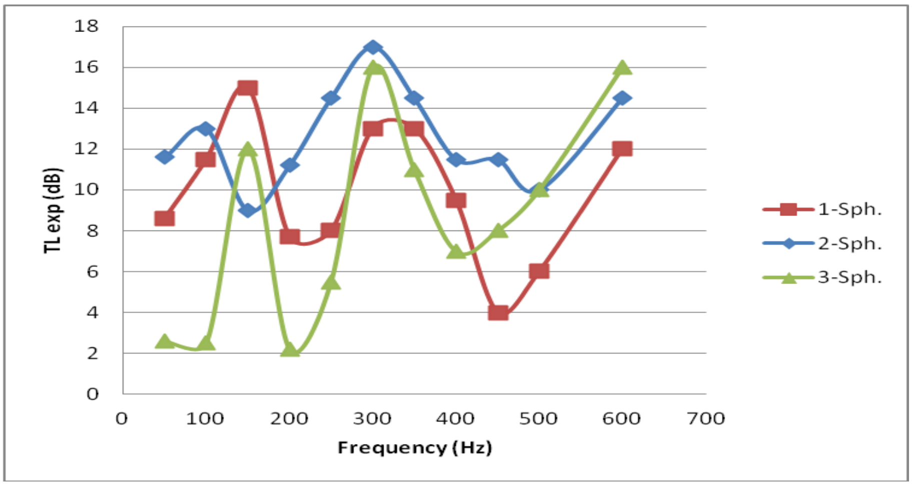


Figure (7): Transmission Losses of spherical silencers in series connection.

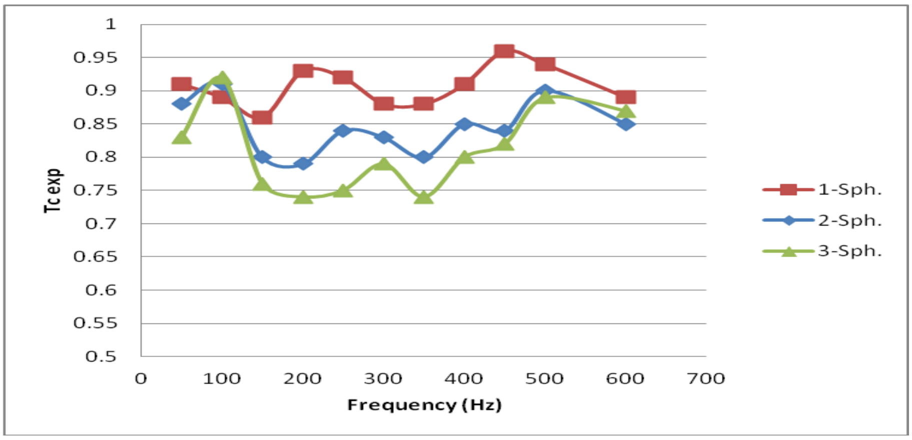


Figure (8) Transmission Coefficient of spherical silencers in series connection.

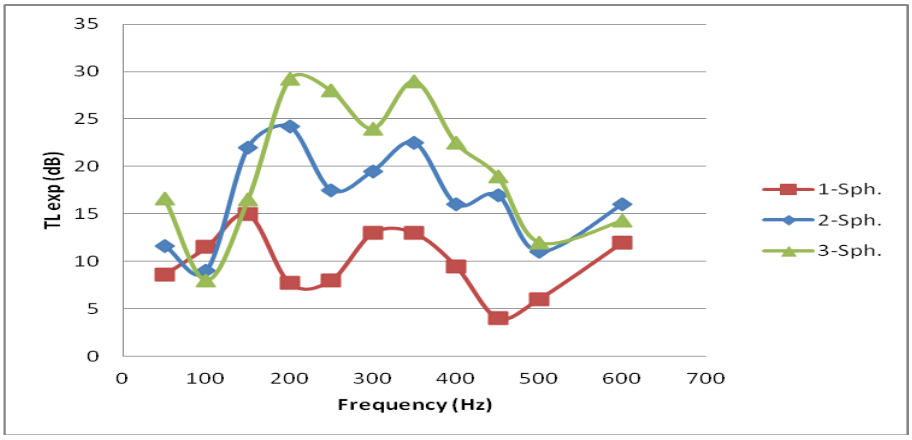


Figure (9): Transmission Losses of spherical silencers in parallel connection.

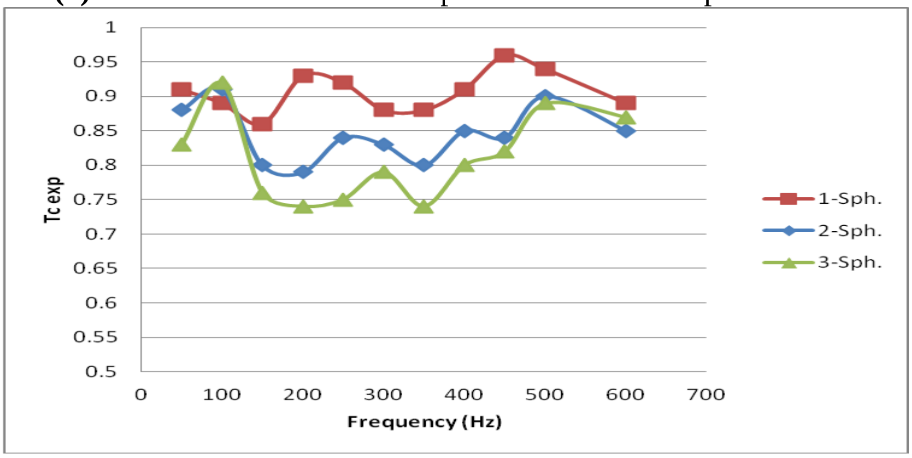


Figure (10): Transmission Coefficient of spherical silencers in parallel connection

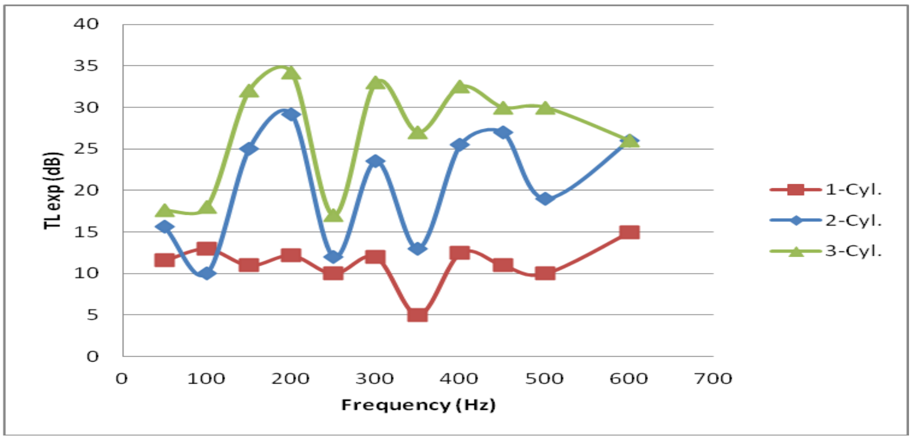


Figure (11): Transmission losses of cylindrical silencers in series connection.

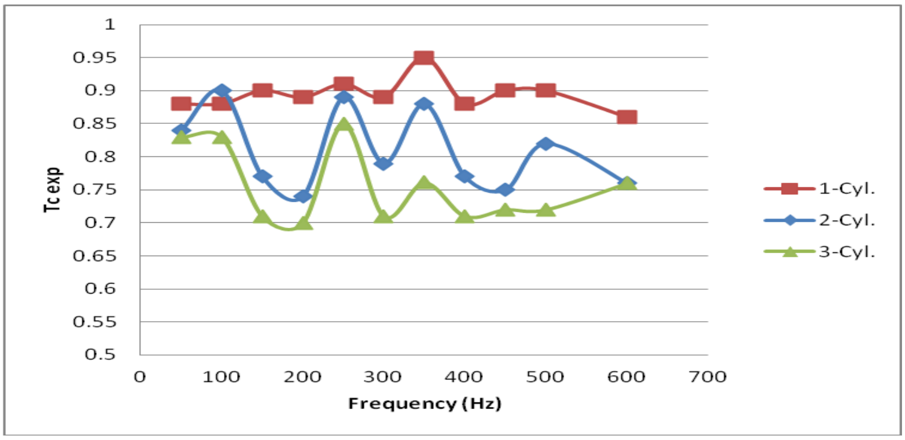


Figure (12): Transmission Coefficient of cylindrical silencers in series connection.

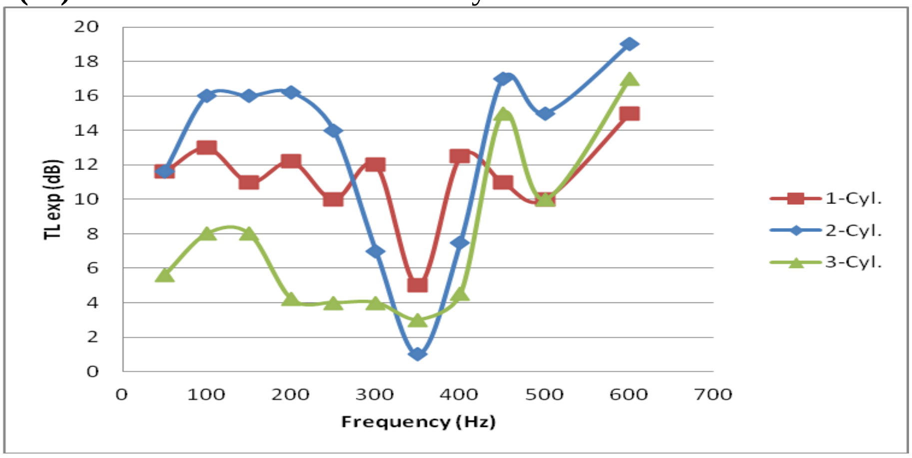


Figure (13:) Transmission Losses of cylindrical silencers in parallel connection.

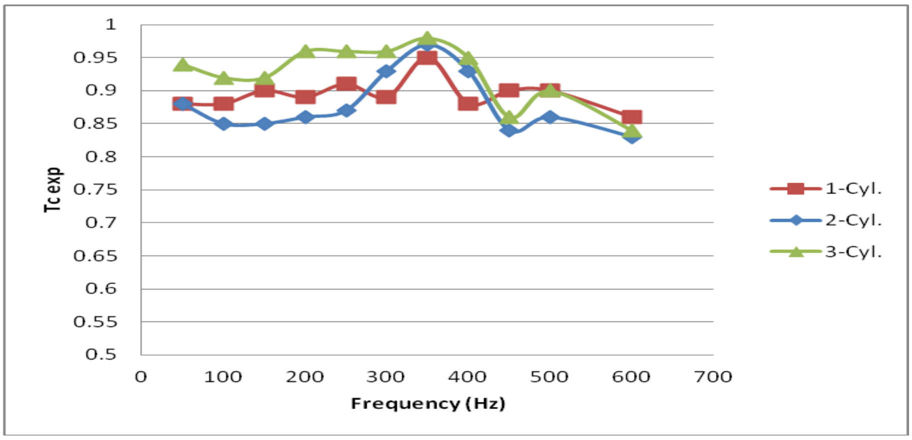


Figure (14): Transmission Coefficient of cylindrical silencers in parallel connection.

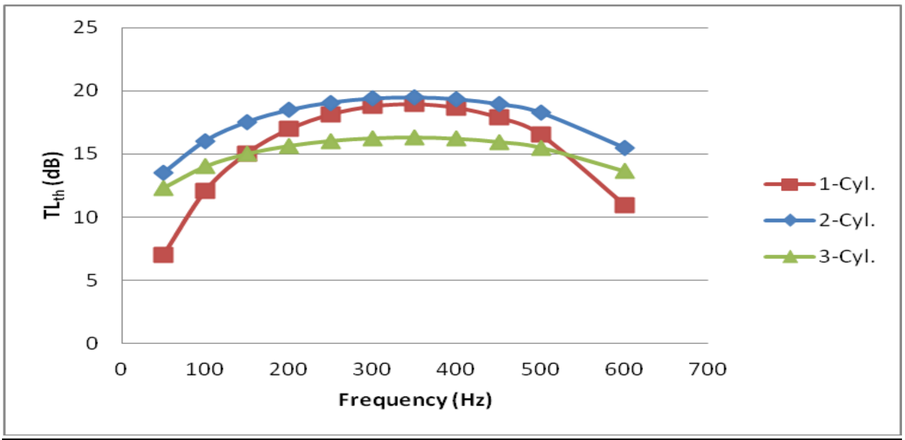


Figure (15) Transmission Losses of cylindrical silencers in series connection.

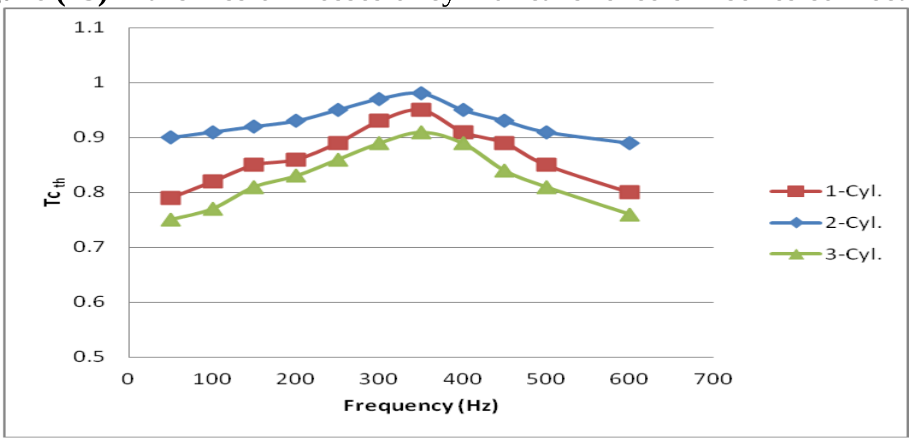


Figure (16): Transmission Coefficient of cylindrical silencers in series connection.

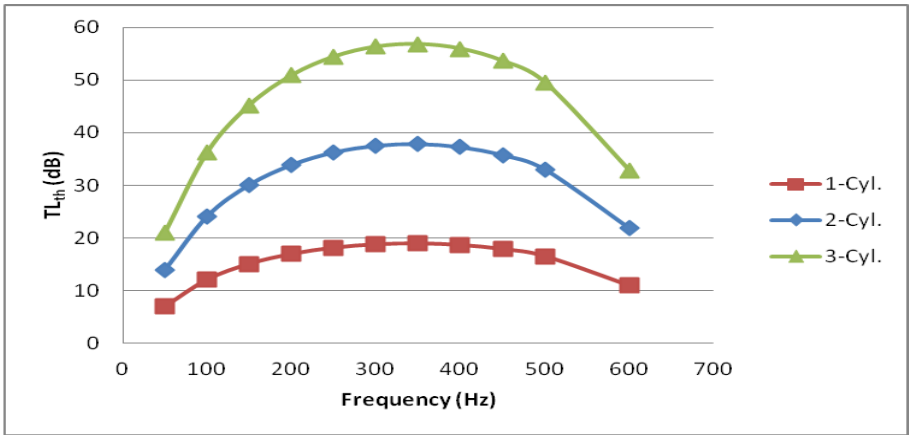


Figure (17): Transmission Losses of cylindrical silencers in parallel connection.

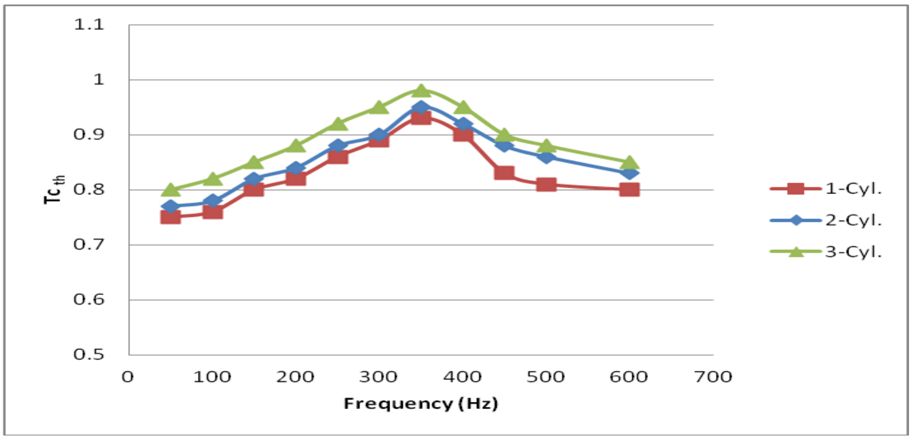


Figure (18): Transmission Coefficient of cylindrical silencers in parallel connection.