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Experimental Study of Orifice Shape Effect on Noise Reduction of Silencer

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Abstract: Noise pollution is one of the most problems caused by internal combustion engines. In this study, the reduction of noise by changing the orifice shapes and inserting tape is experimentally investigation. The effect of orifice shape on noise reduction of silencer is presented. The calculation of transmission losses and transmission coefficient of noise for different shapes of orifice by using MATLAB program is obtained. In addition, the frequency for maximum and minimum losses is obtained. The results showed that the use of the square orifice and helical tape were better options to reduce the noise in the silencer.

Keywords: Orifice, Noise, Silencer, Internal combustion engines, Transmission losses, Transmission coefficient.

1. INTRODUCTION

Noise is a deleterious sound that may hurt your hearing and cause many health problems such as hypersensitivity to noise, stress, and blood pressure increased and heart rate increased. As humans respond in many ways to noise, the level at which the noise will begin to become dangerous is not known. The amount of hurt caused by noise, which depends on the overall amount of energy, was received over time. This means that high noise could cause damage in short time. The normal noise exposures standard in the place is about 85 dB averaged over an eight-hour period. This could not mean that below 85 dB is always safe. This implies that eight-hour exposure to 85 dB noise could lead to an acceptable level of risk to hearing health in the all place.. Impulse noise levels in excess of the peak exposure standard of 140 dB are prepared to be hazardous and capable of causing a little hearing damage. Noise pollution or noise damage is the disturbing or high noise that may harm the creation or balance of people or animal life. The source of the most outdoor noise worldwide is generally caused by devices and transportation systems such as aircraft, motor vehicles and trains [1].

Noise reduction is the abatement of noise after it is creation. Noise reduction is mainly limited to the applications of silencer, acoustic enclosure, partial barrier, and isolations and damping component [1, 2]. The work of the silencer within the exhaust systems of the vehicles is to minimize the noise that produced by the engines in addition its reduced the back the pressure which consequently reduces the engines efficiency. Many silencers have inlet valve, outlet valve, housing, and resonant chamber. The gas after it has flow through catalytic converter is traveled via the inlet valve from the engine. Then the gas has flown out into the housing through a few small holes. The sound waves created by the gas travelling through the system around in the silencer. This trip results in the waves eliminating each other out and thus leads to reducing sound [3].

The silencers can be cracked into three mainly types: reflective, dissipative, and combination reactive-absorptive. As well as to the three main silencer types, other functionality as the spark arresting, emission control, heat recovery …etc. It may also be combined within the silencer design, also the silencer was needed to pass state required soot tests, in addition the silencers may reduce engine temperature and boosts exhaust flow thus reducing wear on the engine parts [4].

Many types and forms of orifices were used in most flow systems (gas or liquid); the orifices are a hole in the vessel, the liquid or gas had flows out through which. This opening or hole was named an orifice so long as the level of the liquid on the upstream portion is over the top of the orifice. The main objective of the orifices is to obtain the discharge. The orifices can be produced in a vertical portion of the vessel or in a base, but the worker one is more known. The orifices may be in different forms depending on their shape, size and nature of discharge.

Danile [5] studied an experimental rig to determine the suitable design for an automotive muffler. Then main principles of muffler design is discussed, when the design of the muffler for many applications consists both acoustic and non-acoustical shape.. The limitation of this muffler (Yoshimura RS-3) are: the inner diameter (57 mm); the diameter of the outer shell (112 mm; length 457 mm; 1.6 mm) perforated tube running from the inlet to the exist pipes with (1160) perforations that are a diameter (3.2 mm). Normal noise reduction results are founded by testing this type of design. Muna et al. [6] presented an experimental study for the effect of inlet and outlet pipe lengths on the noise attenuation in the mufflers. The rig is designed for the reactive muffler. The aim is to reduce the noise level by using many pipe lengths for inlet and outlet discharge tubes (length of inlet pipe 10, 20 and 30 cm and length of outlet pipe 10, 20 and 30 cm). From conclusion the most tall outlets pipe the higher noise attenuation will be get. Muna et al. [7] studied the effect of shape of the pipes on the noise reduction by changing the length of the inlet and outlet pipe and the shape. In addition, the losses in the noise for many shapes have been tested experimentally. The results show that the corrugated pipe is the best for reduction of the noise. Muna et al. [8] investigated experimentally the effect of orifice shape and bore-area on noise attenuation in a reactive muffler. The behavior characteristic and the effect on transmission losses are studied for many types of orifices plate (circle, square, rectangle and triangle) with various bore areas and frequencies. It can be seen from the results that the shape of triangular bore orifice with a little bore area was observed to be the most effective.

The aims of this study is to investigate the acoustic performance of different configurations of orifice plates along the contained silencer and tape around the internal diameter for this silencer in order to reduce the noise of silencer.

2. THEORETICAL ANALYSIS

The speed of sound is the rate at which the wave of sound propagates through the medium, and is depending on the density and elasticity of that medium for all objectives; the speed of sound in air is depending on the absolute temperature only which affects its density directly.

The equation for the speed of sound in air is [10]:

$$C = 20.05 \times \sqrt{T} \quad \text{(m/sec)} \qquad \ldots\ldots\ldots\ldots (1)$$

$$C = \sqrt{\gamma p / \rho} \qquad \ldots\ldots\ldots\ldots (2)$$

Where:

$$\gamma = \frac{Cp}{Cv} \qquad \ldots\ldots\ldots\ldots (3)$$

Where,

λ= Wave length=C/f (m).

f= Frequency (HZ).

The ratio of air at constant pressure to constant volume, for air were listed in the following table:

Table (1): The ratio of air at constant pressure to constant volume for air

Γ	Pressure P (N/m^2)	Density ρ (kg/m^2)	speed of sound at atmospheric pressure C (m/sec)	The temperature (°C)
1.4	1.01×105	1.21	343	20

Sound power level and sound pressure level are generally obtained in terms of decibels, which means that they are not absolute values, but rather measurements relative to reference values. These values are mostly used to measure the strength of a sound wave is the sound pressure level (LP or SPL) measuring according to the standard reference pressure of [4]:

$$P_{ref} = 2 \times 10^{-5} \quad Pa \qquad \ldots\ldots\ldots\ldots (4)$$

The sound pressure level can be calculated using the following formula:

$$SPL = 20\log_{10}(P/P_{ref}) \quad \text{(dB)} \qquad \ldots\ldots\ldots\ldots (5)$$

2.1. Calculation of the Transmission losses

The transmission losses (TL) can be calculated from the following equation [8]:

$$TL = 10\log_{10}[1 + 0.25 \times \left(m - \frac{1}{m}\right)^2 \sin^2 Kl] \quad \text{……………… (6)}$$

$$K = \frac{\omega}{c} \quad \text{……………… (7)}$$

Where,

$$m = \frac{D^2}{d^2} \quad \text{……………… (8)}$$

$$\omega = 2\pi f \quad \text{……………… (9)}$$

Symbols	Description	The value
Ω	Wave angular velocity	
D	The expansion chamber diameter	15 cm
D	The inlet pipe diameter	5 cm
K	Number of waves	
L	The expansion chamber length	24 cm

2.2. Calculation of the Transmission coefficient

The Transmission Coefficient in the silencer can be calculated theoretically from the following equation [9]:

$$T_C = \frac{4}{[4\cos^2 Kl + \left(m + \frac{1}{m}\right)^2 \sin^2 Kl]} \quad \text{……….. (10)}$$

3. EXPERIMENTAL WORK

The test rig in this study consists of the following parts:

1- Function generator: to create sound signals with various frequency and operate (50 HZ to 600 HZ), figure (1).
2- Amplifier: to amplify the signal.
3- Loud speaker.
4-Box: where the loud speaker was placed and it also has inner isolation to eliminate the sound reflection and isolation the sound from the outside sound and noise.
5-Cone: connected to the box to make the sound travels in the path.
6- Pipes: used to connect the silencer with other parts.
7- Silencer.
8- Sound pressure level meter: is the most important part used in the measurement of noise, figure (2). A sound level meter operates by using microphone to sense the sound pressure and electronic circuit to convert the sound pressure to an SPL reading.
9- Orifice: Different design and shapes orifice were used in this work as shown in figure (3).

The signal generator is changing to generate sinusoidal wave signal with different frequency from 50 to 500 Hz with 50 Hz step. The SPL meter values were recorded then the test muffler is putting at the con end and the SPL meter is putting at the mufflers other end. The adhesive paste was used to fix the orifice plates. After the noise tests finished the desired results were recorded.

Figures (4), (5) and (6) present the inside of cylinder silencer, schematic diagram of the test rig arrangement and the test rig arrangement respectively.

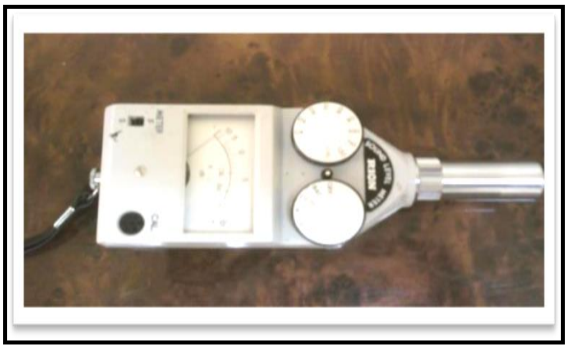
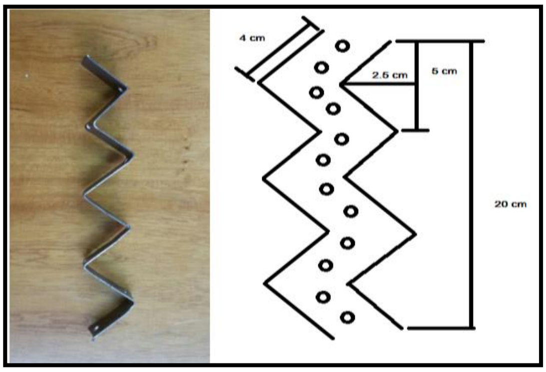
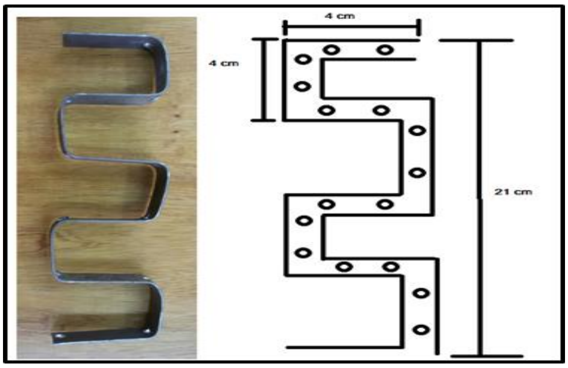
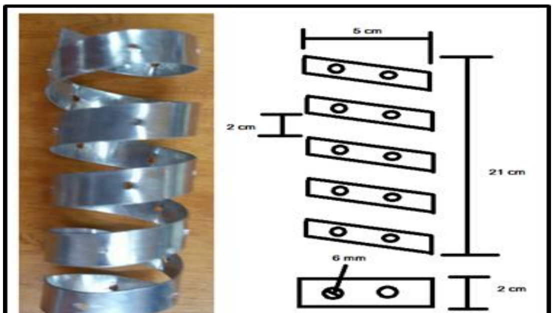


Figure (1): Photo of Function Generator

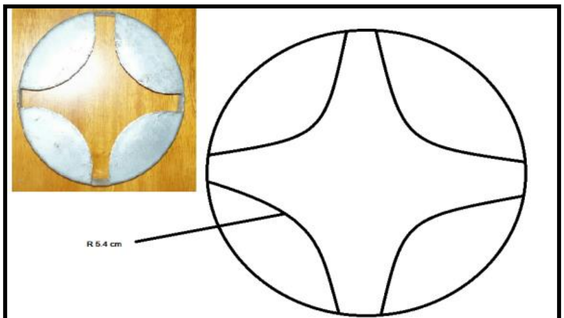
Figure (2): Sound Pressure Level Meter



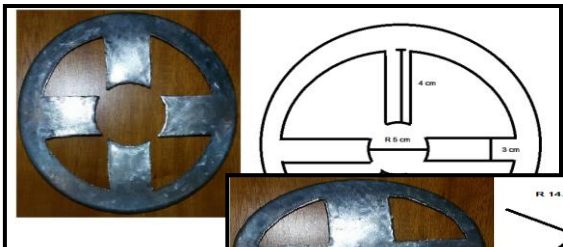




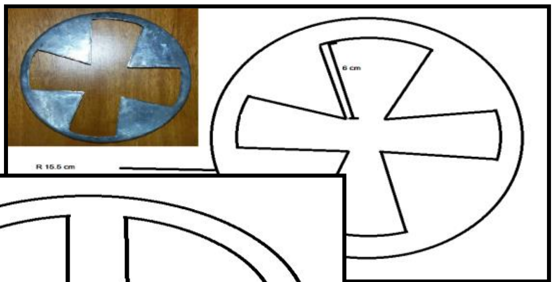
Rectangular & Square

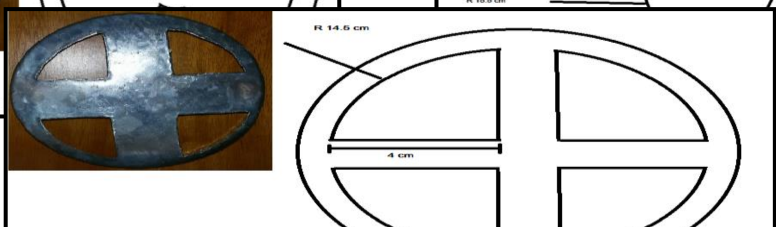


Rectangular & Square



Helical





Circle

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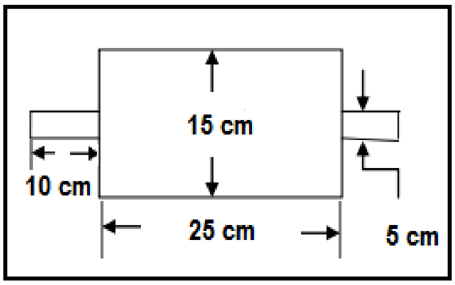
Figure (3): The orifice plate samples



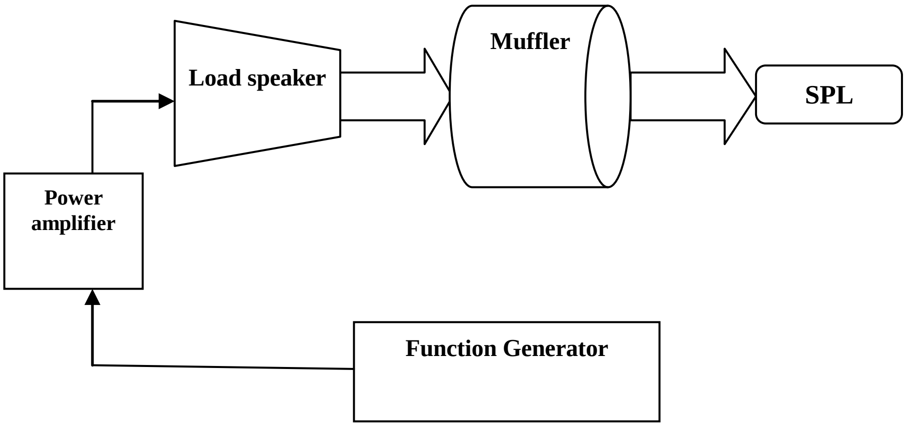


Figure (4): Inside of cylindrical silencer

Figure (5): Schematic Diagram of the Test Rig

Figure (6): The Test Rig Arrangement

4. RESULTS AND DISCUSSION

The experimental results included some calculations to find the values of transmission losses (TL) which equal the difference between SPL1 (sound pressure level) and obtained SPL2, and obtained transmission coefficient (TC) for silencer:

$$TL = SPL1 - SPL2 \quad \ldots\ldots\ldots\ldots.. (11)$$
$$TC = SPL2 / SPL1 \quad \ldots\ldots\ldots\ldots.. (12)$$

Where,

TL= transmission losses TC= transmission coefficient
SPL1 & SPL2= sound pressure levels
The above equations are programmed by using MATLAB program to calculate the TL and Tc experimentally and theoretically.

4.1. Experimental results
4.1.1 Circle Orifice

Figure (7) shows comparison acoustic results of transmission losses against frequency for muffler concepts. The maximum losses for the one circle orifice happened at (50 Hz) and the minimum losses happened at (150Hz). The critical frequencies (50-250) Hz at this range the best of three cases for the two circle orifices but when the range frequencies between (250-600) Hz for the three circle orifices losses are best. While figure (8) shows the transmission coefficient for different range of frequency (50-600) with step 50 for different circle orifice. The maximum transmission coefficient for the one circle happened at (600Hz) and the minimum transmission coefficient happened at (250Hz). But for the critical frequencies (50-250) Hz at this range the best three cases for the three circle orifices and when the range frequencies between (250-600) Hz for the two circle orifices losses are found to be the best.

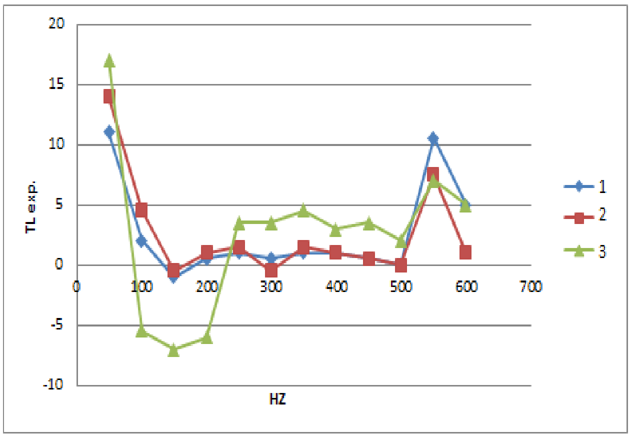


Figure (7): The Transmission losses for Circle Orifice

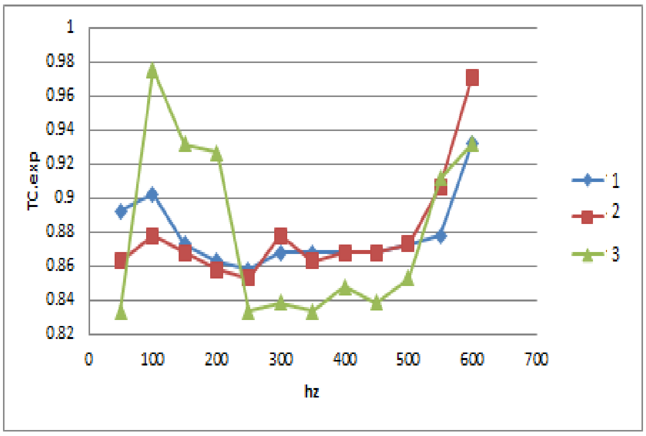


Figure (8): The Transmission Coefficient for Circle Orifice

The transmission coefficient was explained as shown in figure (9) at different frequency for silencers and the maximum coefficient for all cases circle with square and rectangle orifice happened at (50 Hz) and the minimum coefficient happened at (600HZ). In this figure the little different between the three cases can be notices.

The transmission coefficient for different range of frequency (50-600Hz) with step 50 present in figure (10), the maximum transmission coefficient for the circle with square and rectangle orifices happened at (600Hz) while the minimum transmission coefficient happened at (50, 150, 200 and 350Hz). But for the circle with triangle and rectangle orifices the maximum transmission confection occurs at (600Hz) and the minimum transmission coefficient happened at (50, 150, 200, 250, 350 and 450Hz). For the circle with square and triangle orifices the maximum transmission confection happened at (600Hz) while the minimum transmission coefficient occurs at (50, 150, 200, 250, 300,350 and 450Hz)

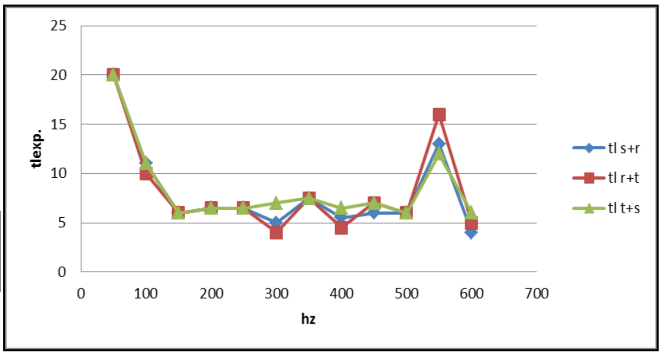


Figure (9): The Transmission Losses for Circle with Multi-Orifice.

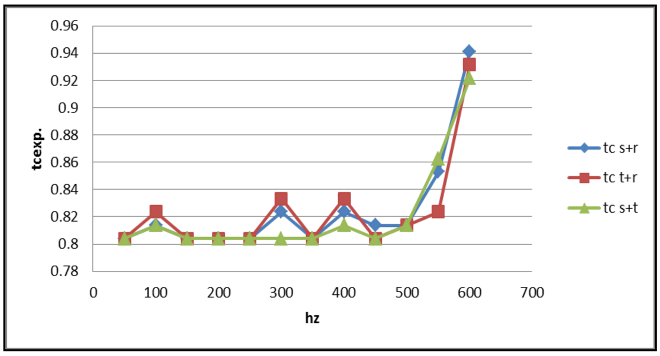


Figure (10): The Transmission Coefficient for Circle with Multi-Orifice.

4.1.2 Triangle Orifice

Figure (11) present the transmission losses at different frequency for silencers and as shown the maximum losses for the one triangle orifice happened at (600 Hz) and the minimum losses happened at (150 and 350Hz). But for the two triangle orifices the maximum losses happened at the frequency of (50Hz) and the minimum losses occurs at (150, 400 and 500Hz). For three triangle orifice the maximum losses occur at (50Hz) and the minimum losses happened at (150, 300 and 500Hz). In this figure shown the little different between three cases.

The transmission coefficient for different range of frequency (50-600Hz) with step 50 for different triangle orifices can be seen in figure (12), the maximum transmission coefficient for the one triangle happened at (100Hz) and the minimum transmission coefficient occurs at (600Hz). But for the two triangles orifice the maximum transmission coefficient happened at (600Hz) and the minimum transmission coefficient occurs at (250Hz). For three triangle orifices the maximum transmission coefficient occurs at (100Hz) and the minimum transmission coefficient happened at (250 and 350Hz).

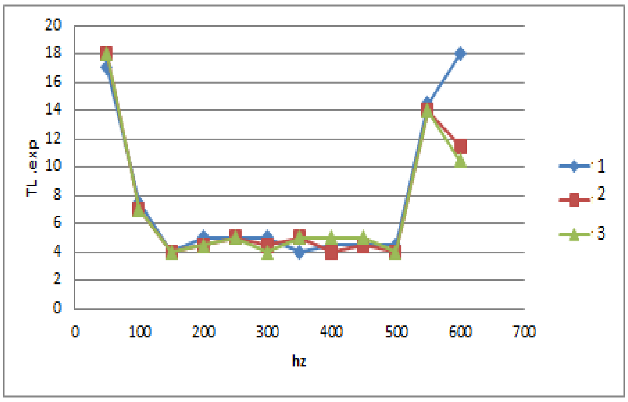


Figure (11): The Transmission losses for Triangle Orifice

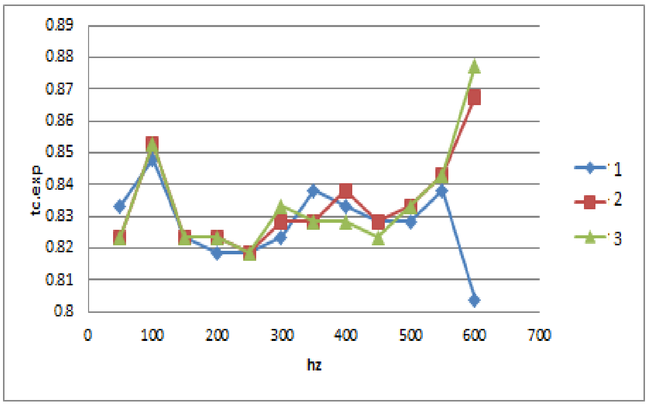
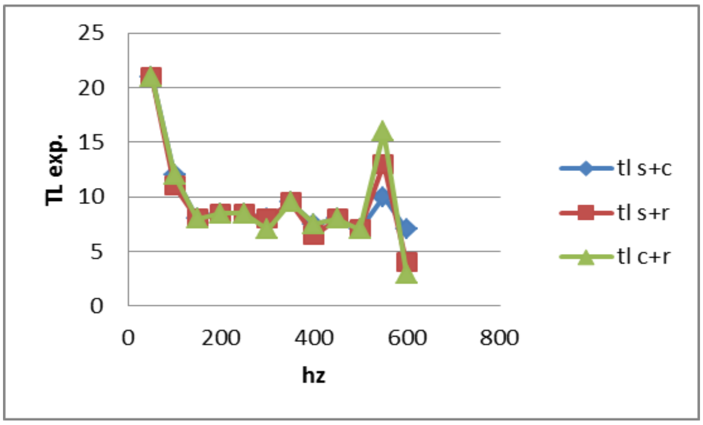


Figure (12): The Transmission Coefficient for Triangle Orifice

Figure (13) illustrates the transmission losses at various frequencies for silencers and as shown the maximum losses for the triangle with square and circle orifices occurs at (50 Hz) and the minimum losses occurs at (500 and 600Hz). But for the triangle with square and rectangle orifices the maximum losses occurs at (50Hz) and the minimum losses happened at (600Hz). For the triangle with circle and rectangle orifices the maximum losses occur at (50Hz) and the minimum losses occurs at (600Hz).

While the transmission coefficient for different range of frequency (50-600Hz) with step 50 seen in figure (14), the maximum transmission coefficient for the triangle with square and circle orifices occurs at (600Hz) and the minimum transmission coefficient happened at (150, 200, 250 and 350Hz). But for the triangle with square and rectangle orifices the maximum transmission convection occurs at (600Hz) and the minimum transmission coefficient occurs at (250Hz). For the triangle with circle and rectangle orifices the maximum transmission confection occurs at (600Hz) and the minimum transmission coefficient occurs at (150, 200, 250 and 350Hz).



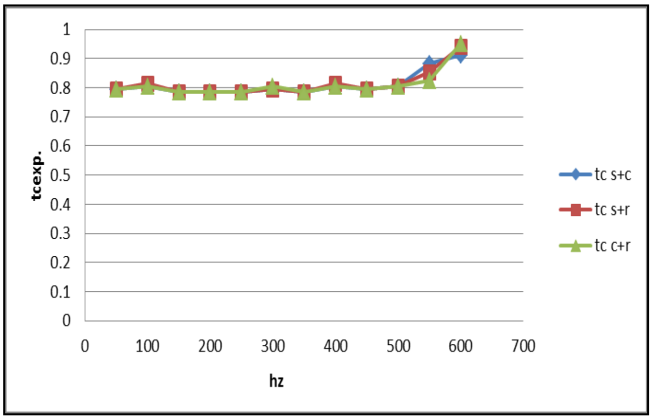


Figure (13): The Transmission losses for Triangle with Multi-Orifice.

Figure (14): The Transmission Coefficient for Triangle with Multi-Orifice.

4.1.3 Square Orifice

Figure (15) clarifies the transmission losses at different frequency for silencers and as shown the maximum losses for the one square orifice occurs at (50 Hz) and the minimum losses occurred at (100, 150, 300, 450 and 500Hz). But for the two square orifices the maximum losses occur at the frequency of (50Hz) and the minimum losses occurred at (500Hz). For three square orifices the maximum losses happened at (50Hz) and the minimum losses happened at (150Hz).

The transmission coefficient for different range of frequency (50-600Hz) with step 50 for various square orifice can be observed in figure (16), the maximum transmission coefficient for the one square occurs at (600Hz) and the minimum transmission coefficient happened at (50, 150, 200 and 250Hz). But for the two square orifices the maximum transmission confection occurs at (600Hz) and the minimum transmission coefficient happened at the frequency (150, 200 and250Hz). For three square orifices the maximum transmission coefficient happened at (600Hz) and the minimum transmission coefficient happened at (50Hz).

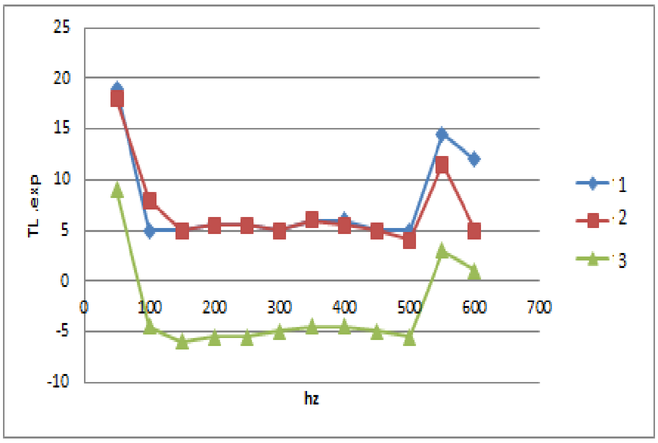


Figure (15): The Transmission Losses for Square Orifice

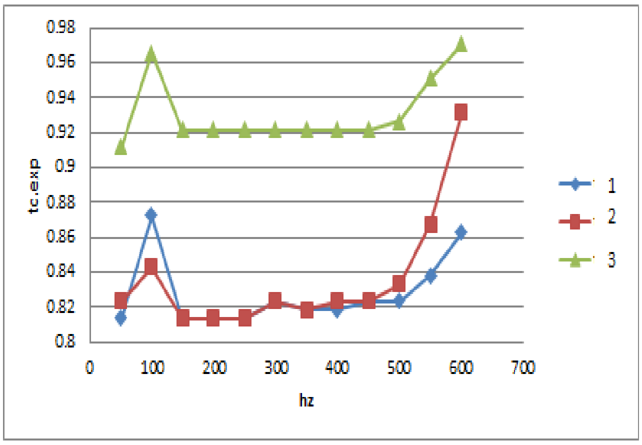


Figure (16): The Transmission Coefficient for Square Orifice.

Figure (17) explains the transmission losses at different frequency for silencers and as shown the maximum losses for the square with rectangle and triangle orifices occurs at (50 Hz) and the minimum losses happened at (300Hz). But for the square with rectangle and circle orifices the maximum losses occurred at (50Hz) and the minimum losses happened at (600Hz). For the square with circle and triangle orifices the maximum losses happened at (50Hz) and the minimum losses occurs at (600Hz).

While figure (18) illustrate the transmission coefficient for different range of frequency (50-600Hz) with step 50, the maximum transmission coefficient for the square with rectangle and triangle orifices occurred at (600Hz) and the minimum transmission coefficient happened at (50, 150, 200 and 250Hz). But for the square with rectangle and circle orifices the maximum transmission confection occurred at (600Hz) and the minimum transmission coefficient happened at (50, 150,200, 250, 350 and 450Hz). For the square with circle and triangle orifices the maximum transmission coefficient occurs at (600Hz) and the minimum transmission coefficient happened at (150, 200 and 250Hz).

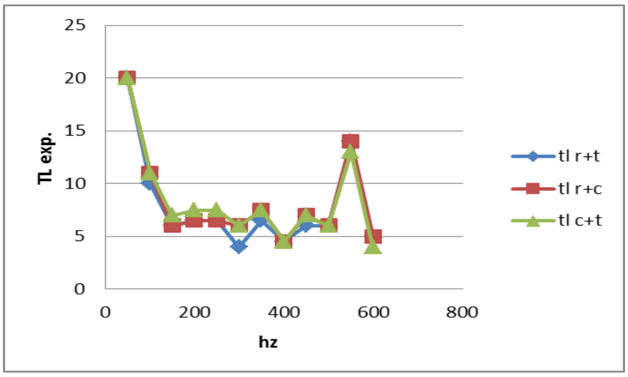


Figure (17): The Transmission Losses for Square with Multi-Orifice

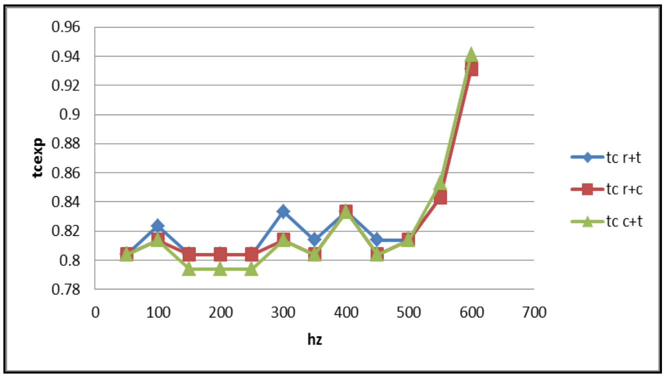


Figure (18): The Transmission Coefficient for Square with Multi-Orifice

4.1.4 Rectangle Orifice

The transmission losses at different frequency for silencers and as shown in figure (19) the maximum losses for the one rectangle orifice happened at (50 Hz) and the minimum losses occurs at (150 and 500Hz). But for the two rectangle orifices the maximum losses happened at (50Hz) and the minimum losses occurred at (150, 200, 250, 300 and 450Hz). For three rectangle orifices the maximum losses happened at (50Hz) and the minimum losses occurs at (150 and 300Hz).

Figure (20) presents the transmission coefficient for different range of frequency (50-600Hz) with step 50 for various rectangle orifice the maximum transmission coefficient for the one rectangle occurs at (600Hz) and the minimum transmission coefficient happened at (50, 150, 200 and 250Hz). But for the two rectangles orifice the maximum transmission convection happened at (600Hz) and the minimum transmission coefficient occurs at (150HZ). For three rectangle orifices the maximum transmission coefficient happened at (600Hz) and the minimum transmission coefficient occurs at (200 and 250Hz).

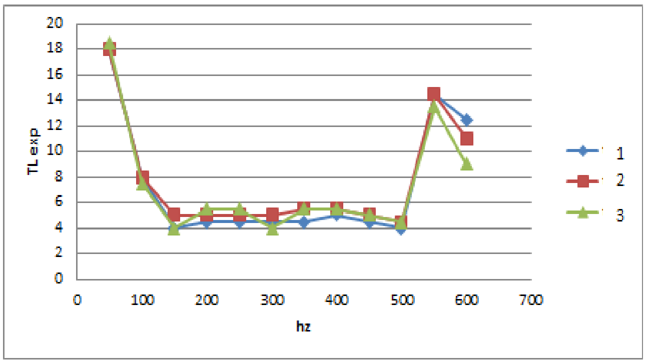


Figure (19): The Transmission Coefficient for Rectangle Orifice

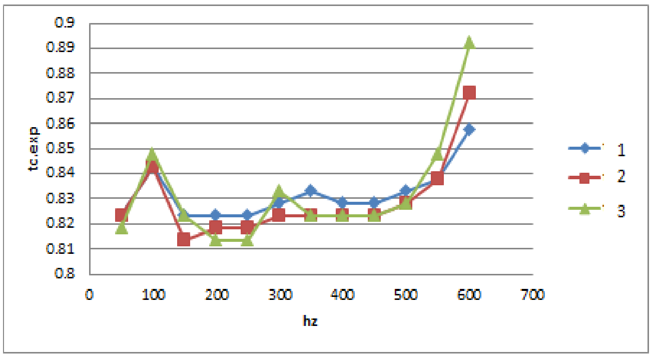


Figure (20): The Transmission Coefficient for Rectangle Orifice

The transmission losses at different frequency for silencers were shown in figure (21) in which can be seen that the maximum losses for the rectangle with circle and triangle orifices happened at (50 Hz) and the minimum losses occurs at (300Hz). But for the rectangle with triangle and square orifices the maximum losses happened at (50Hz) and the minimum losses occurs at (300Hz). For the rectangle with square and circle orifices the maximum losses happened at (50Hz) and the minimum losses happened at (500Hz).

While figure (22) shows the transmission coefficient for different range of frequency (50-600Hz) with step 50, the maximum transmission coefficient for the rectangle with circle and triangle at (600Hz) and the minimum transmission coefficient occurs at (50, 150, 200, 250, 350 and 450Hz). But for the rectangle with triangle and square orifices the maximum transmission confection happened at (550 and 600Hz) and the minimum transmission coefficient occurred at (200, 250 and 350Hz). For the rectangle with square and circle orifices the maximum transmission coefficient happened at (600Hz) and the minimum transmission coefficient happened at (50, 150, 200, 250 and 350Hz).

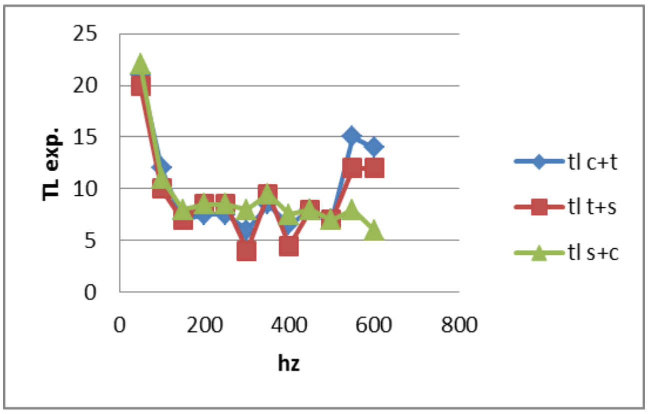


Figure (21): The Transmission losses for Rectangle with Multi-Orifice.

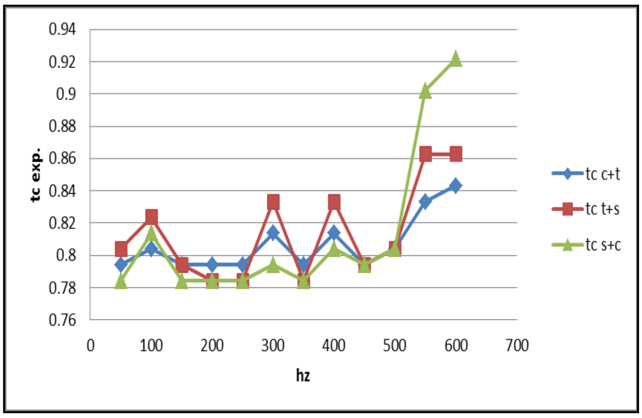


Figure (22): The Transmission Coefficient for Rectangle with Multi-Orifice.

4.1.5 Square Spring Orifice

Figure (23) explaines the transmission losses at different frequency for silencers and as shown the maximum losses for the one square spring orifice happened at (50 Hz) and the minimum losses occur at (200 and 250Hz). But for the two square spring orifices the maximum losses happened at the frequency of (50Hz) and the minimum losses happened at (100Hz). For the three square spring orifices the maximum losses happened at (50, 550 and 600Hz) and the minimum losses occur at (150 and 500Hz).

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The transmission coefficient for different range of frequency (50-600Hz) with step 50 illustrate in figure (24), the maximum transmission coefficient for the one square spring orifice at all frequency except (150, 300 and 450Hz) and the minimum transmission coefficient happened at frequency of (150, 300 and 450Hz). But for the two square spring orifices the maximum transmission confection occurs at (100Hz) and the minimum transmission coefficient happened at (50Hz). For the three-square spring orifices, the maximum transmission coefficient occurred at (100Hz) and the minimum transmission coefficient happened at (150, 200, 250, 300 and 450Hz).

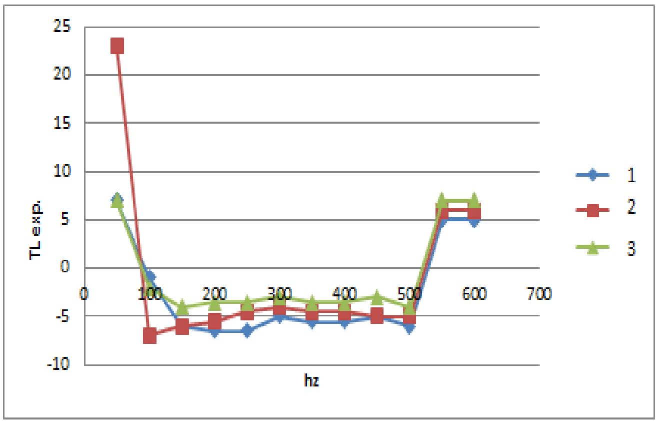


Figure (23): The Transmission Losses for Square Spring

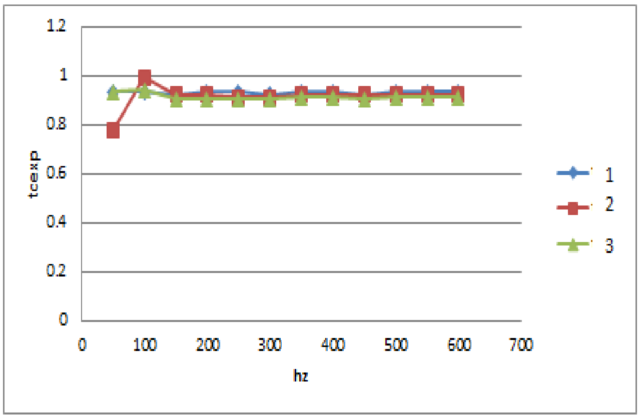


Figure (24): The Transmission Coefficient for Square Spring.

Figure (25) clarifies the transmission losses at various frequencies of silencers, the maximum losses for the one helical spring orifice happened at (50 Hz) and the minimum losses happened at (150Hz). But for the two helical spring orifices the maximum losses happened at (50Hz) and the minimum losses happened at (150Hz). For the three helical spring orifices the maximum losses happened at (50Hz) and the minimum losses happened at (100Hz).

While figure (26) shows the transmission coefficient for different range of frequency (50-600Hz) with step 50, the maximum transmission coefficient for the one helical spring orifice at (100Hz) and the minimum transmission coefficient occurs at (200, 250, and 550Hz). But for the two helical spring orifices the maximum transmission confection happened at (100Hz) and the minimum transmission coefficient occurred at (200, 250, 300 and 400Hz). For the three helical spring orifices the maximum transmission coefficient happened at (100Hz) and the minimum transmission coefficient happened at (150, 200, 250,300, 400, 450 and 550Hz).

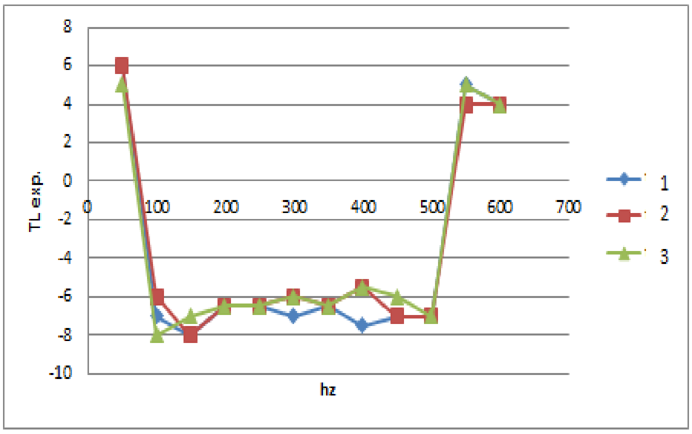


Figure (25): The Transmission Losses for Helical Spring

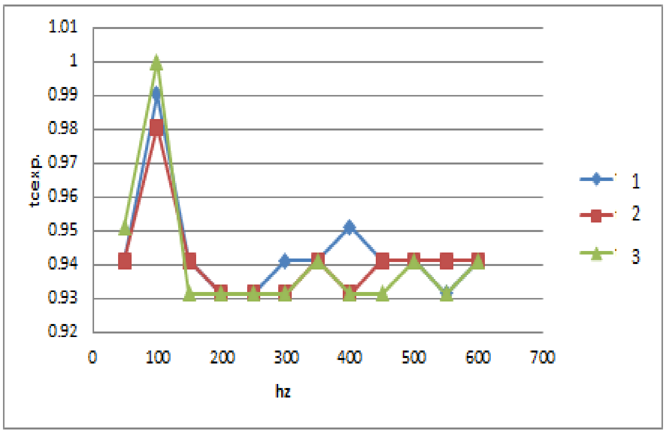


Figure (26): The Transmission Coefficient for Helical Spring.

4.1.6 Triangle Spring Orifice

The transmission losses at various frequencies of silencers are shown in Figure (27) in which can be seen that the maximum losses for the one triangle spring orifice happened at (50 Hz) and the minimum losses occur at (100 and 150HZ). But for the two triangles spring orifices the maximum losses happened at (50Hz) and the minimum losses happened at (150HZ). For the three triangles spring orifices the maximum losses happened at (50Hz) and the minimum losses occurs at (200 and 250Hz).

While figure (28) present the transmission coefficient for different range of frequency (50-600Hz) with step 50, the maximum transmission coefficient for the one triangle spring orifice at (100Hz) and the minimum transmission coefficient occurs at all frequency except (50, 100, 350 and 600Hz). But for the two triangles spring orifices the maximum transmission confection happened at (100Hz) and the minimum transmission coefficient occurred at all frequency except (50, 100, 350 and 600Hz). For the three triangles spring orifices the maximum transmission coefficient happened at (100Hz) and the minimum transmission coefficient happened at (150Hz).

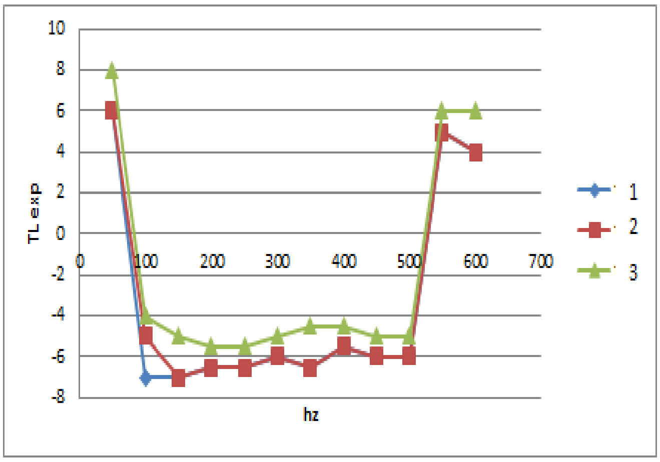
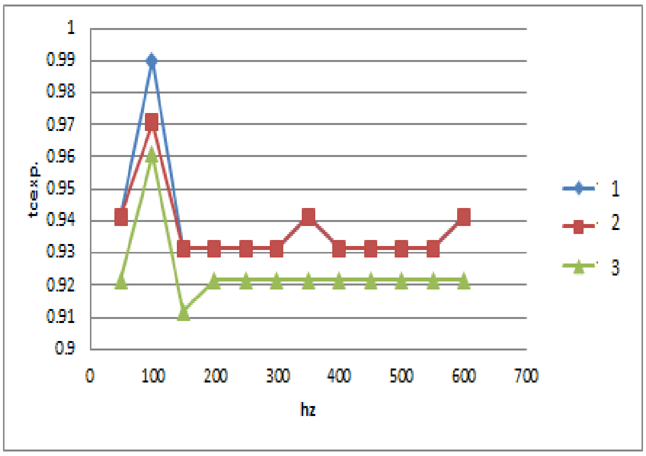


Figure (27): The Transmission Losses for Triangle Spring



(28): The Transmission Coefficient for Triangle Spring

4.2. Theoretical results

Figure (29) shows the transmission losses at different frequency for silencers without any orifice and as shown the minimum losses happened at (50 Hz) and the maximum losses happened at (350Hz).

The transmission coefficient for different range of frequency (50-600Hz) with step 50 illustrate in figure (30), the maximum transmission coefficient at (600Hz) and the minimum transmission coefficient happened at (400 Hz).

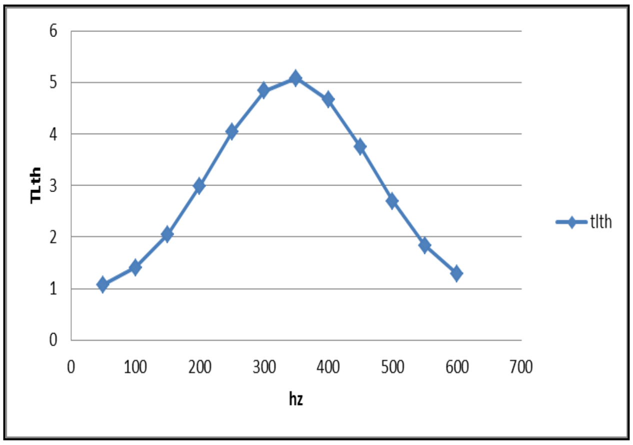


Figure (29): The Transmission Losses Theoretical (TLth)

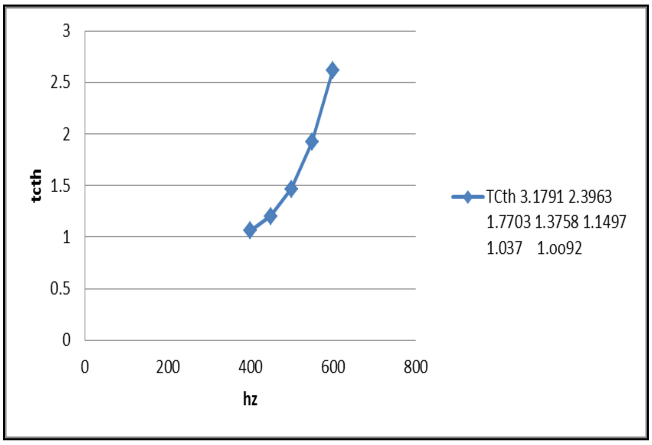


Figure (30): The Transmission Coefficient Theoretical (TCth).

The results showed that the shape of the orifice has an important effect on the reduction of noise in the silencer through the change in the area of the cross section of the orifice. The amount of vibration, then affects the silencer through the different vibrating surfaces and therefore the problem of noise linked with vibration problems.

5. CONCLUSION

The results show hat the using of different shapes of orifice and tape can be reduced the noise. This is clearly evident in using the square orifice and helical tape, where low noise levels are obtained as a result of the use of these types of orifice and helical tape. These types of orifice and tape contain suitable areas to dissipate sound waves and this could affect on the transition of vibration on the surfaces of the silencers. It can also be seen that the transmission losses reduced about (TL=19dB), while the transmission losses for helical tape was about (TL=23dB). These types of orifices can be considered the best in the design of the silencer so that, it can play an important role in many applications of the exhaust system in internal combustion engines.

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