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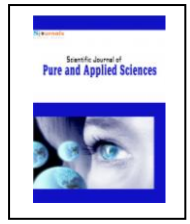

Original article

Alternations in Helmholtz resonator neck angle and the shape of its connection to the air channels to increase the insertion loss of sound

Gh. Pourtaghi[a], F. Valipour[b], H. Mokarami[c], R. Ataeifarid[a,*]
[a]*Health Research Center, Baqiyatallah University of Medical Sciences, Tehran, Iran.*
[b]*Faculty of Health, Baqiyatallah University of Medical Sciences, Tehran, Iran.*
[c]*Faculty of Health- Shiraz University of Medical Sciences, Shiraz, Iran.*

*Corresponding author; Health Research Center, Baqiyatallah University of Medical Sciences, Tehran, Iran.

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A B S T R A C T

Different methods of sound control in industry have been investigated by the researchers. The passive methods such as membrane absorbents, porous absorbents and the sound resonators are among the most important methods of sound control and reduction. In the present study, the effects of changing Helmholtz resonator neck angle relative to the sound channel along with the other alternations in geometric properties of the resonator such as length, cross section and the shape of the cross section were investigated. The circular and rectangular necks with various lengths and shape were used for finding the changes of insertion loss in a cylinder shaped channel made out of PVC with 3 m long and diameter of 9 cm and the thickness of 2.7 mm. The level of insertion loss of sound would be higher in comparison with 45 and 90 degree angles. The rectangular shaped neck exhibited the least efficiency in sound reduction while the conical shaped neck whose base attachment to the sound channel has circular shape resulted in highest level of sound dissipation. The shorter necks with larger cross sections, in comparison with longer necks with small cross sections, would lead to higher insertion loss of sound.

1. Introduction

Sound is an unwanted acoustic wave caused by the vibration of the air molecules and could have destructive effects on human health (Passchier-Vermeer and Passchier, 2000) In order to decrease the sound, the acoustic absorbents such as porous absorbents (like foams, mineral wool, woven absorbents) and resonator absorbents which are based on the Helmholtz resonator principles, have been widely used (Dequand et al., 2003). Nowadays, the use of Helmholtz resonators is expanding and numerous researches have been conducted in order to increase its efficiency and extend its application (Zhao and Morgans, 2009). Helmholtz resonator is composed of a balloon like enclosure which has a hole in opening and would be put on the path of the sound (Ma et al., 2009). If the dimension of the hole on the enclosure, relative to the wavelength of the colliding wave, is small, the air in the hole in response to the collision of the sound wave, would act as a mass and the air in the enclosure would behave like a spring, over all, this setup makes a Helmholtz resonator (Chen et al., 1998). Helmholtz resonator has been regarded as one of the most practical devices in sound controlling by the passive methods and due to its high efficiency in controlling the low frequency and narrow band in the surrounded spaces, it has found a wide spread application (ZM. Environmental and Architectural Acoustics, 2004). The combination of Helmholtz resonator and the sound insulators could enhance its efficiency (de Jong et al., 2011). In ventilation systems, as a result of fan performance in a constant speed or the turbulence of the air flow, a sound would be created with a fixed frequency range which could propagate in the channel and enter the room (Chatellier et al., 2004). For the purpose of controlling these types of sounds, use of dispersive silencers is not a proper choice as these slicers have low efficiency in low frequencies (Selamet et al., 2005). Therefore the simultaneous use of a resonators such as Helmholtz resonator, which due to strong dissipation have excellent efficiency in control of the low frequency sounds, is recommended (Kook et al., 2002; De Bedout, 1996). Helmholtz resonator is a suitable device for resolving the problem of audio recording studios (Bistafa et al., 2012). Since its efficiency could be enhanced for a wide range of frequencies just by covering it with the acoustic absorbents (Cox and D'antonio, 2009). The importance of Helmholtz resonators has attracted the attention of many engineers and researchers, and in the last decades, widespread attempts have been made to enhance and improve the efficiency of Helmholtz resonator. In a study, Li investigated the effect of a Helmholtz resonator installed in a sound channel on the gas route (Li, 2010).

The main mechanism of Helmholtz Resonator is compressing and expanding of air in the cavity. The frequency of Helmholtz resonator was given in equation1.

$$f_H = \frac{c}{2\pi}\sqrt{\frac{A}{V_0 L}} \qquad (1)$$

Here V0 is the cavity volume, A is the cavity neck surface area and L is the corrected vertical length of the cavity neck. The relation between the real vertical cavity neck height L0 and L = L0 + l, where l is the end correction factor to account the added resonating mass and the speed of sound which is generally c = 340 m/s.

Where the mass of air and the specific ratio of heat inside the neck are given the equation 2 is present the resonant frequency equation (Bothien and Wassmer, 2015).

$$\omega_H = \sqrt{\gamma \frac{A^2 P_0}{m V_0}} \qquad (2)$$

The impact of a varying Helmholtz resonator on the insertion loss of sound has been studied by Oliver (Cherrier et al., 2012). In 2001, Griffin et al proposed the connection of a Helmholtz resonator with a dispersive silencer to increase the amount of insertion loss of sound (Griffin et al., 2001). Utsumi explained the method of applying varying volume of Helmholtz resonator by Termination Impedance Control of a Side branch Resonator to reduce the sound produced in Ducts (Utsumi, 2001). Guan and Jiah tested the installation of the resonators on sound channels with three different degrees of freedom for the purpose of sound reduction (Changbin and Zongxia, 2012). Sun et al conducted some studies on analysis of the sound due to centrifuge compressors and reducing that by application of the Helmholtz resonators (Sun et al., 2006). The insertion loss of sound induced by Helmholtz resonators in the air intake systems was examined (Selamet et al., 2001). By combining the resonator and the absorbents, Steve succeeded to increase the amount of sound transmission (Esteve and Johnson, 2005). In order to decrease the sound in the pneumatic systems used muffler (Zhao et al., 2006). Today, mufflers and sound obstacles are widely used as the main component of sound reducing in the sound transmission channels (Yasuda et al., 2013). Many researchers such as Salis and Sharples have successfully employed the sound obstacles along with Helmholtz resonators in open and internal spaces for controlling the sounds with different frequencies (De Salis et al., 2002). In addition to industrial applications of Helmholtz resonator, nowadays, there are many of noises such as transportation and military industries that should be controlled (Pourtaghi et al., 2014). Regarding the mentioned studies and also the stability and strong performance of Helmholtz resonator, this device has been considered as a proper choice for sound controlling purposes. Since the properties of the resonators have the crucial acoustic role in insertion loss of sound (Selamet et al., 2005; Tang, 2005). The present research was performed on the basis of this hypothesis that the angle and the shape of the resonator neck relative to the channel could be effective on the sound transmission loss.

2. Materials and methods

A cylinder shaped resonator in which there is a piston to make the internal volume of the resonator variables was installed at one meter distance from the sound source which created sound in a cylinder shaped channel made out of PVC with 3 m long and diameter of 9 cm and the thickness of 2.7 mm. All the components were completely sealed. In such situation, the diameter of the resonator was kept fixed and its volume could be changed via a bar attached to the piston. Three different types of neck, including cylinder, rectangular and conical shape necks, were prepared, and the amount of insertion loss of sound by the resonator in various situations with different necks were separately investigated. A Speaker which was placed in a cube with 20 cm dimension was applied as the sound source, in a way that the constructed system was similar to impedance tube; the only difference was that the Helmholtz resonator was installed in the sections where the sound insulators were to be placed. In fig 1 the place of resonator attachment to the microphone on the constructed sound tube could be observed. In order to measure the level of sound pressure in the frequencies of 63, 125, 250 and 500 Hz, a sound level meter (CEL- 620), which was calibrated each time before the measurement by a calibrator (CEL-120), was employed. The Speaker was attached to an amplifier and a sound generator.

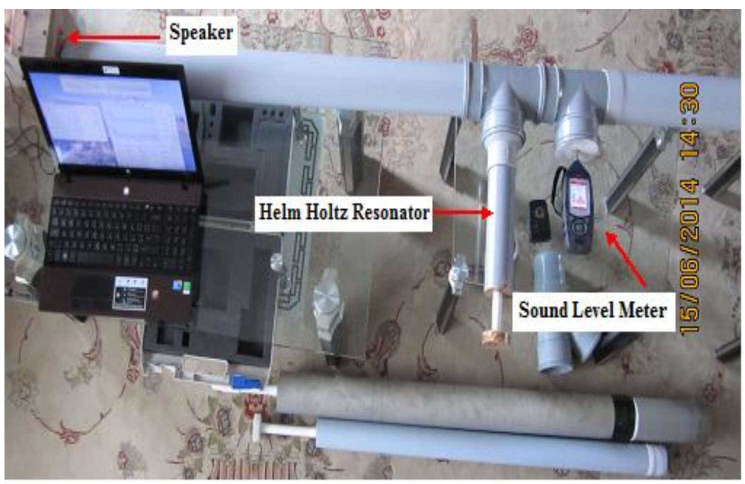

Fig. 1. Helmholtz resonator system used in this study.

In order to prevent from consideration of the increasing effect of the background level in the level of sound pressure, the amount of the background sound pressure level was tightly measured. In each frequency, a sound with pressure level of 114± 0.2 dB was generated. The circular and rectangular necks with lengths of 15, 25 and 50 mm had the cross section areas of 176, 452 and 906 mm^2, and 6 type of conical neck with small and large cross section areas of (961- 452), (1256- 452), (2041- 452) and (1589- 907), (2001- 907) and (2640- 907) mm^2 with 30, 50 and 79 mm lengths were used.

Also, since the conical shape necks could be circular in the place of attachment to the channel, and in order to investigated the effect of the attachment place shape, two conical necks each of which was a conical shaped with cross section of (2732- 346) with the length of 70 mm, and the other one which was circular in the place of attachment to the sound channel with cross section area of 346 mm^2 while the cross section of the conical shaped was 2732 mm^2, were evaluated. In the last experiments, the effect of the neck angle relative to the channel (45, 90 and 135 degree) on the amount of sound pressure level reduction by the Helmholtz resonator was investigated.

3. Results and discussion

The obtained results show that the proposed alternations in the manner of resonator neck attachment to the sound channel such as the attachment angle and the shape of the neck would result in changes in the amount of insertion loss of sound in the channel.

The results of the transmission test and sound loss observations in the constructed system revealed that among the investigated circular necks and in different frequencies, the one with 34 mm diameter and 15 mm length has the highest amount of insertion loss of sound (table-1). Also, in the range of various frequencies, the neck with 15 mm diameter and the length of 50 mm showed the lowest amount of insertion loss of sound among the circular necks under study.

Table 1
Insertion loss of sound of the circular necks with different diameters and in various frequencies.

Neck length (mm)				Frequency	Sectional area
50	25	15		(Hz)	(mm^2) of Neck
21.8	26.9	29.2	Insertion Loss(dB)	63	**176**
21.5	24.6	26.3		125	
16.2	21.1	23.2		250	
2.5	6.2	8.9		500	
30.4	31.7	36.2		63	**452**
27.5	28.8	29.7		125	
27.3	28.6	32.8		250	
6.1	8.2	12.2		500	
34.4	38.5	39.4		63	**907**
30.2	30.6	31.8		125	
34.8	36.9	37.2		250	
17.4	20.7	22.8		500	

According to table 1, the highest insertion loss of sound in the neck with different length and diameters was observed in frequency of 63 Hz, and frequency of 500 Hz had the least amount of insertion loss of sound among various frequencies.

The effect of the rectangular necks, whose length and cross section area were similar to the circular necks, was also investigated. This type of necks, in comparison with the circular ones has less insertion loss of sound.

The Helmholtz resonator with conical shape necks with dimensions of: 30, 50 and 70 mm long; and cross section areas of (961, 452), (1256, 452), (2041, 452), (1589, 907), (2001, 907) and (2640, 907) mm^2 were tested. Table 2 indicates the amount of insertion loss of sound for the conical shaped necks.

Table 2
Insertion loss of the conical shaped necks in various frequencies.

Sectional areas of two sides of conical necks (mm^2)– Neck length (mm)								Frequency (Hz)
(2640-907)-70	(2001-907)-50	(1589-907)-30		(2041-452)-70	(1256-452)-50	(961-452) -30		
36.7	37.7	37.8	Insertion Loss(dB)	35.3	36.7	35.3	Insertion Loss(dB)	**63**
29.4	30.1	31.9		29.4	29.7	30.2		**125**
35.5	36.2	36.7		31.3	31.8	30.5		**250**
23.7	23.7	23.9		16.9	16.2	16.9		**500**

Regarding table 2, it can be understood that the highest amount of insertion loss of sound, namely 37.8 dB, belongs to the neck with the length of 30 mm and the cross section areas of (1589, 907) mm^2, also, the lowest amount of insertion loss of sound, 16 dB, is associated with the length of 50 mm and the cross section areas of (1256, 452) mm^2. Moreover, the results showed that, according to table 2, the highest induced insertion loss in the necks with different lengths and cross section areas was for the frequency of 63 Hz, whereas the least amount of insertion loss of sound in the necks with varying length and cross section areas was observed in the frequency of 500 Hz. In continue, the impact of the circular and conical shaped necks on the total amount of insertion loss of sound was investigated. In a way that, at the beginning the pressure level of 114± 0.2 was generated in each frequency, and then the effect of the resonator on the total sound pressure level was examined. Fig 2 depicts the transmission loss in two necks with the length of 50 mm and the cross section areas of 452 and 907 mm^2; and two conical shape necks with the length of 50 mm and the cross section areas of (1256- 452] and (2001- 907) mm^2.

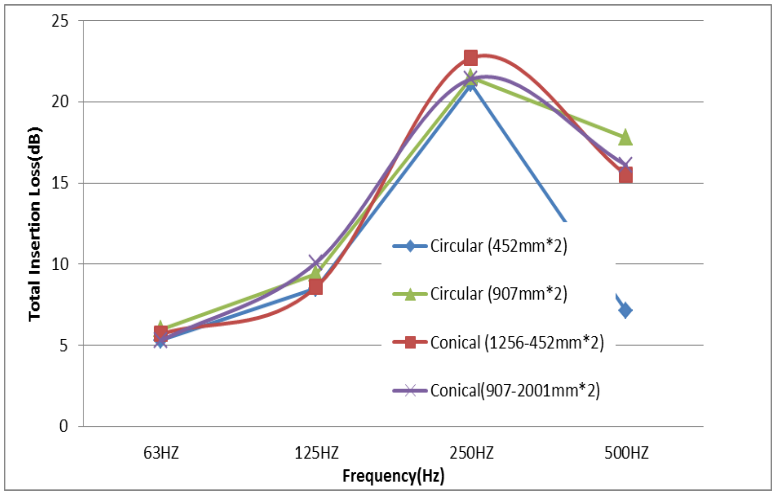

Fig. 2. Comparison of the insertion loss in the circular and conical necks.

The highest total insertion loss was for the conical shape neck with cross section areas of (1264- 452) mm^2 and the lowest amount of total insertion loss was attributed to the circular neck with cross section area of 452 mm^2. The highest insertion loss (22.7dB) was achieved for the frequency of 250 HZ", while the lowest amount of insertion loss was associated with the frequency of 63 Hz. Therefore, according to these results the sound problem in the frequency of 250 Hz could be solved by the conical shape neck with cross section of (1256- 452) mm^2; and the noise problem on the frequencies of 63 and 500 Hz could be properly resolved by a circular neck with cross section area of 907 mm^2, while the conical shape neck with cross section area of (2001- 907) mm^2 is a suitable solution for the sound problem in 125 Hz frequency. In order to study the effect of the circular part, tow necks, one conical shape with the length of 70 mm and the other a conical shape neck with a circular part with the length of 25 mm and diameter of 25, and a conical part with 70 mm long were investigated, and their results are depicted in Figure 3.

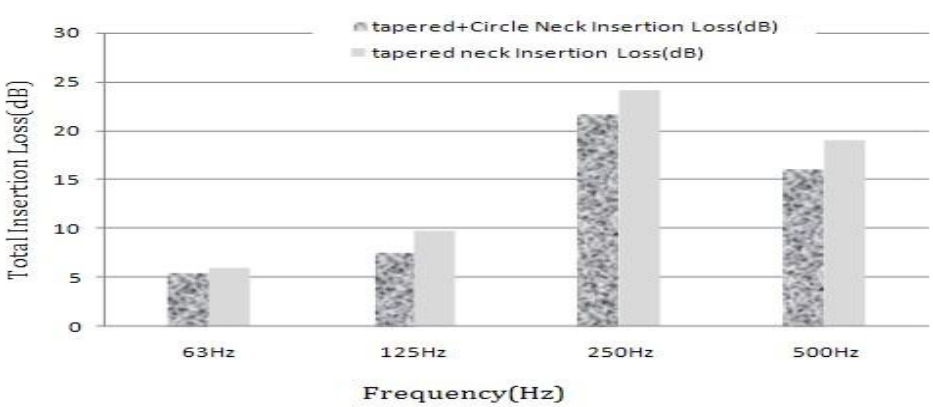

Fig. 3. Total insertion loss of the conical neck with and without a circular part.

As it can be seen in (Fig 3), the presence of the added part to the neck resulted in decrease of total insertion loss in all the frequencies. In some frequencies the effect of this added part on the insertion loss is low, while in some other it had a significant effect. In order to examine the influence of the angle between the resonator neck and the channel on the amount of insertion loss in a specific frequency, the resonator neck was placed with 907 mm^2 in sectional area and three different angles: 45, 90 and 135 degree, and its effect was studied, the results are shown in (Table 3).

Table 3
Comparison of insertion loss in resonators located in different angles with.

Angle				Frequency (Hz)
135	**90**	**45**		
37.2	37.9	36.5	Insertion Loss (dB)	**63**
30.5	31.4	30.3		**125**
35.9	34	35.6		**250**
24.1	19.5	17.9		**500**

Insertion loss (IL) measurements in every angles showed that the amount of IL in different angles had some differences, which were small in some angles, while in some other angles the difference was significant. The results also revealed that at the frequency of 500 Hz and the neck angle of 45 degree the IL amount was 17.9 dB, this amount was 19.5 dB at the angle of 90 degree, and 24.1 dB at the neck angle of 135 degree. Therefore, under the condition of this study, the amount of insertion loss in 135 degree was higher than the other investigated angle, 45 and 90 degree. Therefore it can be concluded that in the field of sound control by means of a Helmholtz resonator, studying the angle between the resonator neck and the channel in the dominant frequency could affect the value of insertion Loss.

The neck of the resonator which was made in a conical shape in different lengths was effective on the amount of insertion loss, and the results in this content was compatible with the results obtained (Tang, 2005). In this study, comparing the results of the two conical shape each of which was circular in the place of attachment to the sound channel and the other one was attached to the channel unchanged, showed that the amount if insertion loss of the circular conical neck was lower than the other one. This indicated that when the conical shape necks are applied, the non- conical shape parts must be eliminated. Other methods have also been proposed to enhance the efficiency of the resonator that many of them would lead to increase of resonator dimension, like the study conducted by Liu et al which showed that the simultaneous installation of the Helmholtz resonator in series could help in reducing the sound caused by the centrifuge compressors (Liu and Hill, 2001). This method would result in increase of resonator volume, while in this study, by adjustment and changing the angle between the resonator neck and the sound channel, it is possible to achieve a proper sound decrease. In this case adding other resonators and simultaneous application of several resonators were only used for some specific frequencies such as 63 Hz in which its elimination was faced with some limitations. There are some other methods such as the system proposed by Meissner in which by use of vibration the resonator was stimulated; but this method would increase the total cost of insertion of sound (Monkewitz and Nguyen-Vo, 1985). While in the presented study there was no increase of cost. In the other work presented by Zhao and Morgan, in order to increase the efficiency of multiple resonators, the resonators were adjusted and displaced in air transmission path (Selamet et al., 2001). or in another research, Xiaofeng achieved to higher efficiency of sound control by application of active methods in sound elimination (Zhao and Morgans, 2009). It has to be noted that in all studies such as the works done (Shi et al., 2013). Or the study made by Peat (Peat, 2010) or the one conducted by Subramoniam (Nair et al., 2010). The Helmholtz resonator was installed at the angle of 90 degree with the air channel.

4. Conclusions

The results of this study show that by changing the shape and the installation angle of the resonator relative to the sound channel, it is possible to increase the amount of insertion loss in a sound channel. Moreover, it was revealed that generally speaking, in such a system by increase of the frequency the value of insertion loss in specific frequencies would decrease, by making some alternations in the angle and the shape of the Helmholtz resonator attachment to the channel, it is possible to increase the insertion loss of the resonator without any changes made to its dimension. While the present study which proposed the changing of the resonator installation angle, in some frequencies especially at the frequencies of 63, 250 and 500 Hz, installation of the resonator neck with 135 degree angle relative to the channel lead to increase of insertion loss, which was even better than achieved with the use of active methods of sound reduction or resonators with excess components added.

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