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Noise reduction efficiency of Helmholtz resonator in simulated channel of HVAC system

Hossein Ali Yousefi Rizi, Farhad Forouharmajd, Somayeh Bolghanabadi

Department of Occupational Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

ABSTRACT

Aims: The purpose of this article was investigating the efficiency of designing resonator in decreasing low noises.

Materials and Methods: The designed Helmholtz resonator was installed in a channel analogous to ventilation channel. The resonator was produced signals at very low frequencies (125-500 Hz) and sound pressure levels 60-90 dB and transmitted through a channel by means of a speaker. Afterwards, the variation of sound pressure level was monitored and then intra-channel signals processing and preparing of sound Algorithm in channel was done by MATLAB software.

Results: The highest decrease of sound pressure level at 125 Hz frequency among of Helmholtz resonators was observed at chamber diameter of 63 mm and resonator's 1 cm-caliber. Sound pressure level reductions of 0-10 dB were achieved in an experimental duct system using a Helmholtz resonator.

Conclusions: This research showed that the designed Helmholtz resonators at a certain frequency of low-frequency sound demonstrated the soundest decrease. The increase in the Helmholtz resonators' chamber volume and their neck's pass area are negatively associated with the rate of sound resonance. As a result, of determining the effective frequency range of the Helmholtz resonator, the designed resonator could be applied as an effective and efficient instrument of removing or decreasing noise.

Key words: Channel, Helmholtz resonator, HVAC system, noise reduction, silencer

Address for correspondence:
Dr. Farhad Forouharmajd, Department of Occupational Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: forouhar@hlth.mui.ac.ir

INTRODUCTION

With the turn of industrial systems to new industrial technologies, human beings will be potentially subject to numerous problems socially, economically, psychologically, and physically. In this regard, one of the consequential problems of human society is the presence of more than licensed noise in the workplace and living environment.

The significance of noise and noise pollution not only is distinct in the cases of hearing loss and occupational deafness, but also noise exerting an indirect influence upon human beings has remarkably pernicious effect on heart and digestive organs,[1-7] circulatory and nervous systems.[2,8,9] It also leads to cramping, physical and mental (psychic) fatigue, dizziness, loss of balance, cardiac disease, which taken together trigger

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exhaustion and impatience (in human being)[2,10,11] which lowers mental and decrease of mental process and decreases work efficiency.

The followings are the consequences of encountering low-frequency noise: Tinnitus, headache, rise in the rate of cortical secretion, increase of stress response, respiratory disorders and expression of resentment and complaint.[12,13]

Many scholars have defined low-frequency noise as broadband noise within the frequency range of 20-200 Hz and some scholars did define it within the range of 10-250 Hz.[14,15]

Nowadays, the field of noise control has entered a wider phase. In European countries, most of the academic scholars and experts of controlling noise pollution, given the irrecoverable consequences of noise in industrial societies and environments, are attempting to find ways to decrease and control noise in the sources of sound generation. Given the extensive researches conducted on lowering noise and its unwillingness and some of its irrecoverable consequences at work and living environment, the scholars have come to this stage of belief that decreasing noise pollution at the source of sound generation would be the best and most promising controlling way.[3,16,17]

Hence, we'd better in accordance with the proper principles and through systematic programming and controlling methods in source or throughout the path of sound transmission get to decrease this very problem as much as possible.[18]

In most of the industries, there is too much noise as a result of air or gas transmission from one section to another section.

This type performs by reflecting sound energy back toward the source, thereby canceling some of the sound energy. Because there is both an entrance and exit discontinuity, sound is reflected from two points.[19]

It is imperative to make use of particular equipment's called noise reducers (silencer) or acoustic filters to reduce noise pollution. There are two approaches to controlling acoustic noise: Passive and active. The traditional approach to acoustic noise control uses passive techniques such as enclosures, barriers, and silencers to attenuate the undesired noise. Passive silencers use either the concept of impedance change caused by a combination of baffles and tubes to silence the undesired sound (reactive silencers) or the concept of energy loss caused by sound propagation in a duct lined with sound-absorbing material to provide the silencing (resistive silencers). Reactive silencers are commonly used as mufflers on internal combustion engines, while resistive silencers are used mostly for duct-borne fan noise. These passive silencers are valued for their high attenuation over a broad frequency range. However, they are relatively large, costly, and ineffective at low frequencies, making the passive approach to noise reduction often impractical. Furthermore, these silencers often create an undesired back pressure if there is airflow in the duct.[20-22]

A muffler or silencer is an instrument within the category of sound resonators which could be found in different forms and in terms of the kind of usage in sound source and air path precludes the transmission of sound waves and does not affect any tangible resistance against the path of air or gas passage. In the very kind of reaction resonator, there are used principles of geometric design rather than substances of sound resonance. One kind of this silencer is Helmholtz resonator, which is appropriate for low and below — 200-Hz frequencies — like what in fan and channel noise.

The Helmholtz resonator in terms of form and its structural design for its very feature of being spongy, forthwith trapping the wave energy reduces the noise.[23,24] Temporary, it removes the unwanted noise through generating anti-noise which is of the same amplitude with the first wave but in opposite phase. Effective removal depends upon the recognition of sound wave features and exact anti-noise generation.[19]

Helmholtz resonator is appropriate for low frequency noise and of course, below — 200 Hz frequencies.

The problem of noise concerning the tune in low frequencies is the fundamental and the main problem of industries. This very piece of research is being conducted for most of the noise produced in industries — that are within the low-frequency range and the most serious problem of the industries. For this reason, the application of the Helmholtz resonator, which is appropriate for frequencies below 200 Hz, is being suggested. The purpose of this article is investigating the efficiency of designing resonator in decreasing low noises, in this regard, with determining the effective frequency range of the Helmholtz resonator in noise reduction of a channel, this resonator could be used as an effective instrument of noise removal of the fan and channel.

MATERIALS AND METHODS

This is an analytical and experimental study. The designed Helmholtz resonator was being installed in a channel analogous to ventilation channel with the size of 30 cm × 30 cm and 2 m long. Helmholtz resonators through different frequencies reduce the mentioned noise.[25] The resonator holds a resonance frequency, which is determined in terms of air cavity resistance and air mass in neck length. In the resonance frequency, or through an incoming wave will become stirred and highly vibrated, because hollow resistance during air inertia at the time of friction plays a nominal role in dynamic range. Such a balance brings about the removal of incoming wave acoustic impedance and theoretically the element of pressure reaches zero at the narrow opening of the resonator.

Herman Helmholtz in 1962 explained in-detail the issues of resistance and mass. The simple form of Helmholtz resonator is comprised of a sphere or spherical chamber and a narrow channel which has a tapered neck which is attached to the edge of that channel [Figure 1].[26]

In order to make the Helmholtz resonator two types of material are used; polyvinyl chloride (PVC) pipe and Medium-density fiberboard (MDF) wood. MDF thickness which is equal to 16 mm constitutes the L part of the Helmholtz resonator and the resonator's holes (10, 20 and 30 cm). In general, in this very experiment we managed to design nine Helmholtz resonators with different size and volumes. In order for the already designed resonator to be able to produce below 500 Hz frequency it is needed to precisely specify the static volume of the chamber, speed of sound, cross-sectional area and the length of resonator's channel. For the purpose of determining such factors and frequency limit (the frequency with the greatest deal of resonance), we can exploit the following formula which enjoys the following features:[27]

$$f = \frac{v}{2\pi}\sqrt{\frac{A}{VL}} \qquad (1)$$

Where f is the Helmholtz resonant frequency, v is the speed of sound in the gas, A is the cross-sectional area of the neck, V is the static volume of the cavity and L is the neck length. Ideal Helmholtz resonance the period of resonance (T), is proportional to the square root of the volume of the cavity. The period of resonance of a designed Helmholtz resonator is given by

$$T = \frac{2\pi}{v}\sqrt{\frac{VL}{A}} \qquad (2)$$

Resonance at a given frequency, the relationship between the height of the air column (h) and the length of the neck (L) of an ideal Helmholtz resonator can be shown to be

$$\frac{1}{h} = \frac{4\pi^3 r^2 f^2}{Av^2} L \qquad (3)$$

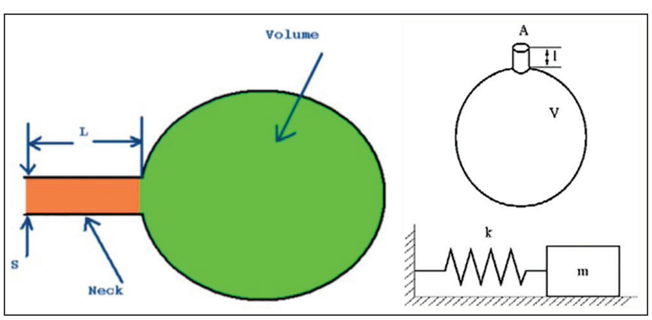

Figure 1: Basic diagram of a Helmholtz resonator

Like the Figure 2, Helmholtz resonator is designed in line with standardized principles and installed on the channel path. Afterwards, a microphone at a certain distance from Helmholtz resonator was attached to channel to measure pressure and swing range

By means of MATLAB software[28] (signal processing and generation software), there were produced very low frequencies (125-500 Hz) and transmitted throughout a channel by a speaker, that speaker mounted at the end of the duct served as the pressure source during this measurement (control source was stimulated by a closed-loop adaptive control strategy to change the resonance frequency), and microphone's signal will be recorded on the system.

Before installing Helmholtz resonator, low frequencies generated as well and the rate of sound level will be recorded on the set (system). Ultimately, comparing the sound pressure balance before and after the concrete presence of Helmholtz resonator, the rate of decreased sound at different frequencies would be considered. The task of processing intra-channel signals and preparing sound algorithm in the channel was carried out through MATLAB software.

RESULTS

After constricting the channel and Helmholtz resonator considering the standard figures (numbers) derived from the frequency formula,[19] In order to gain the low frequencies (below 500 Hz), firstly a taken action toward the microphone sampling before sound generation was done, The results of the measurement signal were considered at low-frequency loudspeaker generator in four different frequencies 60, 70, 80, and 90 Hz for Helmholtz absorber in nine different sizes. The results of measurement and sampling of low-frequency sound signals derived from LABVIEW and analysis of sound data through MATLAB software [Figures 3-6].

In this method, signals with the frequencies of 125-250-500 Hz were analyzed as low-frequency noise. In the following

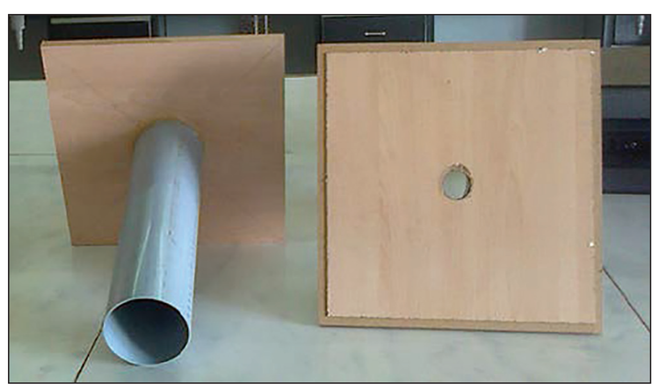
Figure 2: The two Helmholtz resonators pictured here have two different neck diameters

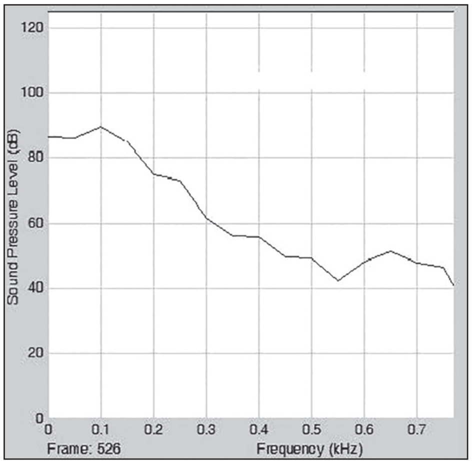

Figure 3: Signal measured at a frequency of 125 Hz before installing Helmholtz resonator

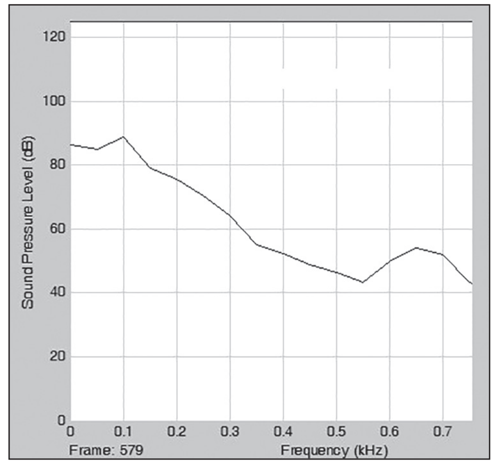

Figure 4: Signal measured at a frequency of 125 Hz after installing Helmholtz resonator

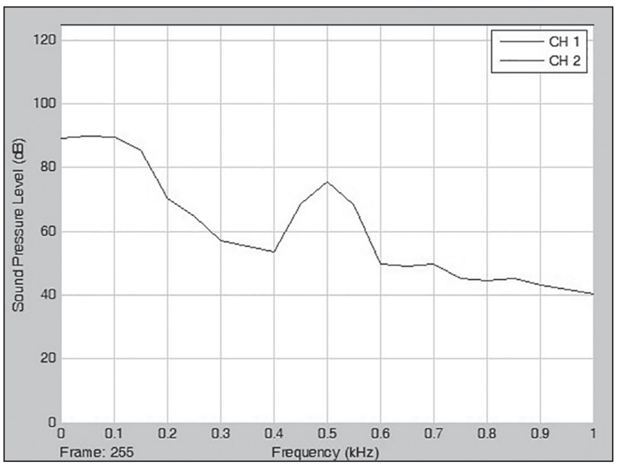

Figure 5: Signal measured at a frequency of 500 Hz before installing Helmholtz resonator

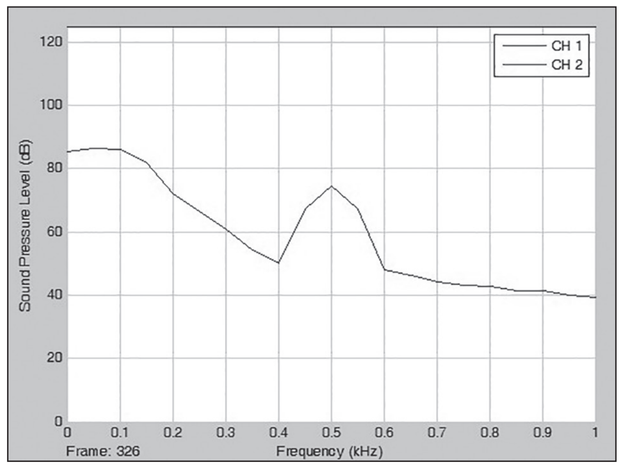

Figure 6: Signal measured at a frequency of 500 Hz before installing Helmholtz resonator

tables, there are provided data regarding the measured frequencies in Helmholtz resonators, the resonators with a volume diameter of 63 mm and caliber's diameter of 10, 20, and 30 mm.

Table 1 is showing Noise reduction rate in the diameter size of 63 cm and 10 cm opening diameter Helmholtz resonator. Another diameter size including 20 and 30 mm has been bring in Tables 2 and 3. Considering the conducted measurements, and also given above tables, among Helmholtz resonators the 125 Hz frequency, which holds the 63 mm-diameter resonator's chamber and resonator's 10 mm-caliber, showed the most decrease.

Increasing the frequency brings on the decrease in resonance rate through resonators.

The data also demonstrated (in the data table) that in the frequency of 125 Hz there is a negative relation between resonator's caliber and the rate of sound resonance.

The measured signal at the 125 Hz frequency is demonstrated in below diagram, which is indicative of decrease rate at this frequency; the rate of measured sound before Helmholtz resonator installation is 88 Hz. After the installation of Helmholtz resonator there could be traced a decrease of sound to the extent that it reaches 78 dB.

DISCUSSION

This research was conducted to investigate the resonator's efficiency in reducing the rate of low-frequency sounds in channel. During the design process of this resonator for which we used MDF wood and PVC pipe, several factors were involved to reduce the noise made by the speaker so that we may have the maximum attenuation. One of these factors is the location of Helmholtz resonator on the channel. That is to say, that exact point be right on the spot where could be exerted the maximum pressure.

Table 1: Noise reduction rate in the diameter size of 63 cm and 10 cm opening diameter Helmholtz resonator

Frequency (Hz)	Sound pressure level (dB)	Effective height (cm)	Preabsorbent (dB)	After installation adsorbent (dB)	Noise reduction (dB)
125	60	7.5	88	78	10
	70	7.5	86	79	7
	80	7.5	83	77	6
	90	7	92	91	1
500	60	5	85	82	3
	70	5	76	75	1
	80	5	82	82	0
	90	5	86	86	0

Table 2: Noise reduction rate in the diameter size of 63 cm and 20 cm opening diameter Helmholtz resonator

Frequency (Hz)	Sound pressure level (dB)	Effective height (cm)	Preabsorbent (dB)	After installation adsorbent (dB)	Noise reduction (dB)
125	60	1	90	87	3
	70	1.5	86	82	4
	80	1.5	80	74	6
	90	1.5	91	87	4
500	60	2	67	64	3
	70	2	76	76	0
	80	2	82	82	0
	90	2	90	88	2

Table 3: Noise reduction rate in the diameter size of 63 cm and 30 cm opening diameter Helmholtz resonator

Frequency (Hz)	Sound pressure level (dB)	Effective height (cm)	Preabsorbent (dB)	After installation adsorbent (dB)	Noise reduction (dB)
500	60	4.5	88	86	2
	70	4.5	83	81	2
	80	4	86	85	1
	90	4	90	90	0

One other factor is the exact adjustment of the piston to be precisely located on resonator in order to determine the chamber volume, exact location of the microphone on the channel.

In a similar experiment, Birdsong and Radcliffe[29] and De Bedout *et al*.[30] utilized PVC pipe to make Helmholtz resonator. In another study, there was used a Helmholtz resonator made up of plastic.[31]

Corning was investigated relationship between the neck length of a spherical resonator and its period of fundamental resonance. This was done by measuring the frequency of fundamental resonance of the resonator at six different neck lengths.[32]

Given the results of this study, Helmholtz resonator showed the most decrease in the frequency of 125 Hz and the least decrease in the frequency of 500 Hz.

Also among derived data, at the frequency of 125 Hz there was the soundest decrease in the 10-mm diameter. Diameter increase is negatively associated with the rate of sound resonance and also with the increase in Sound pressure level from 60 Hz to 90 dB we saw a decrease in the rate of sound resonance.

Among Helmholtz resonators, those which had a smaller chamber diameter showed by far higher rate of resonance. That is to say, there was a negative association between the increase of diameter and the rate of resonance. The diameter of 63 mm demonstrated the maximum (rate of) resonance, and in the resonators with the diameter of 63 mm, resonators with the small mouth diameter demonstrated the most rates of resonance; in the sense that there was a negative association between diameter increase and the rate of sound resonance.

In addition, at the frequency of 500 Hz in which we saw the least rate of sound decrease, the most sound decrease pertains to a resonator with a caliber equal to 10 mm; in the sense that it showed a negative association between this diameter increase and the rate of sound resonance and also in line with the increase of sound level at the frequency of 500 Hz we saw a decrease in the rate of sound resonance.

At other frequencies in which the measurements were carried out, smaller-caliber resonators showed the more rate of resonance than bigger-caliber ones.

According to investigations already made by Corning, resonance in one short length neck resonator is way different from a long neck one.[32]

Increase in noise levels and resonator's chamber volume were negatively associated with the rate of sound resonance. The resonance frequency could be controlled without any change in the chamber volume and merely through changes in the height of the neck, the texture and form of the resonance.[33]

Also Selamet *et al*. is shown that the acoustic performance of a Helmholtz resonator may be modified considerably by the density and thickness of the fibrous material without changing the cavity dimensions.[34]

What could be deduced from such results is the highest power of the low-frequency noise in ventilation and transmission systems in the channel, which brings on some proved and irrecoverable consequences upon individuals and society.

According to what was already provided on the significance of low-frequency sound and the analysis of transmitting signals and channel's acoustic data, we attempted to point out the significance of investigating low-frequency sounds.

CONCLUSION

This research showed that the designed and installed Helmholtz resonators on a channel at a certain frequency of low-frequency sound can be effective on the noise decrease. This very decrease was more obvious in smaller resonators. In addition, the increase in the Helmholtz resonators' chamber volume and their neck's pass area are negatively associated with the rate of sound resonance.

As a result, determining the effective frequency range of the Helmholtz resonator could be applied as an effective and efficient instrument of elimination or decreasing noise.

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