Original Article

The estimation of Helmholtz resonator and active noise control to predict noise reduction of fan in an air duct

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ABSTRACT

Aims: The main goal of this paper was to evaluate the effectiveness of Helmholtz resonator in noise reduction of duct equipped with active noise control (ANC).

Materials and Methods: Noise frequency band was produced by a propeller fan, which was spread into a plexiglas duct. The noise was formed by digital signal processing (DSP) to estimate the anti-noise which spreads along the duct to postpone the primary noise as a response to DSP. In this method, fan noise was recorded with a microphone. The anti-noise with the same amplitude was reproduced, and the reverse phase postpones the original noise at the primary noise path by a speaker. The designed Helmholtz resonator was installed on the duct for detecting the reduction noise at the tonal interest frequency of 300 Hz. Helmholtz resonators can give sound attenuation at a narrowband of frequencies, close to its resonance frequency. The overall decline changes were estimated in order to predict the effectiveness of the method.

Results: In this study, a noise discount of 5-10 dB at the peak frequencies has been observed. The peak frequency of residual noise has reduced 5-10 dB. The value is more than applying ANC system solely to optimize noise lessening of produced noise by a fan along the designed duct.

Conclusion: Use of Helmholtz resonator is proposed as a suggestion to optimize the process of noise fall in duct. This study is concerned with the attenuation of tonal noise transmission in ducts by using ANC and side branch resonators together.

Key words: Active noise control, Helmholtz resonator, noise reduction

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INTRODUCTION

The problem of low-frequency tonal noise is inherent to industries that use machineries such as internal-combustion engines, compressors, fans, blowers, power transformers and gearboxes. Low-frequency noise (0-500 Hz) and infrasound (0-20 Hz)[1] create some serious hearing and non-hearing disease and impairment among the workers who are suffering. The infrasound frequency is a small part of low frequencies,

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but so important in terms of vibration hazards that made scholars try to solve the problem of noise exposure.[2] The need is ever-present for industry to reduce the annoyance caused by the humming nature of tonal noise, not only to workers within an industry, but also to the surrounding community. Depending on the application and cost constraints, tonal noise transmission can be controlled in different ways such as installing reactive silencers, barriers, side branch and active noise control (ANC).[3] There are two approaches to control acoustical noise: Active and passive.[3] The traditional approach to acoustical noise control uses passive techniques such as enclosures, barriers, and silencers to attenuate the undesired noise.[3] The work described here is concerned with the attenuation of tonal noise transmission in ducts by using ANC and side branch resonators, simultaneously. ANC is an electro-acoustic feed-forward system with two microphones to receive the produced signals from reference and error sections. The system is enabled to reproduce a signal with the same amplitude of the primary signal but in a shifted phase. For the Helmholtz resonator to be effective within the duct, it was necessary to place the resonator at a location in the duct where there was greatest pressure. In this case, the estimation of two methods has been done to show the overall noise decline. The acoustic sound levels of the created tonal noise must meet three basic criteria: First, the sound levels must not pose a health hazard to the crew; second, the sound levels should not affect crew performance; and thirdly, the sound levels should support a habitable and comfortable living and work environment. In the present paper, it is tried to optimize noise reduction generating by fan and propagating along the duct by cancellation process and Helmholtz resonator.

MATERIALS AND METHODS

The methodology of this study has been designed in two parts/the method is designed according to two separate sections. In the first part, ANC has been designed which tries to decline the noise frequency band produced by the fan. It is clear from the earlier sections that the filtering system is typically designed focusing on the frequency of 120-600 Hz. The interest frequency of 300 Hz is taken from the noise graph of fan with most pressures of sound. In the second step, the resonator will be design based on the interest frequency of 300 Hz to achieve a more cut of frequency.

Designing the setup

This is an experimental study done using an active and passive noise control method. Frequency noise band is produced by a propeller fan, which will reproduce in a Plexiglas duct, with the dimensions of 20 cm × 20 cm × 150 cm. The noise is generated by digital signal processing (DSP); the anti-noise spreads along the duct to cancel the primary noise as a response of DSP. The specialized DSP has been designed for real-time numerical processing of digitized signals. These devices enable the low-cost implementation of powerful adaptive algorithms and encourage the widespread development and application of ANC systems based on digital adaptive signal processing technology.

An electro-acoustic device that cancels unwanted sound by generating an anti-noise (anti-noise) with equal amplitude,[4] and an opposite phase as an ANC system[5] have been introduced. The cancellation signal is transferred to the duct by a speaker through data-acquisition card (DAQ) output. A system setup of ANC and Helmholtz resonator is viewed in Figure 1.

Active noise control

System needs to treat itself in a proper way to cancel the whole noise and decrease the error. In this method, fan noise is acquired via a microphone, and the anti-noise with the same amplitude has been reproduced and the reverse phase at the primary noise path via a speaker cancels the original noise. MATLAB software designed by MathWorks from US is to simulate and process signals and create anti-noise by DAQ card.[6]

In this paper, we are considering a noise propagating in a duct as a single directional noise with a low variation of frequency into analysis. Noise signal spreading in a duct is taken to a computer through a DAQ card. This signal is analyzed by computer and forms a signal with the same amplitude but 180° phase shift. This signal is passed through the duct by DAQ card like what is shown in Figure 2. Two signals and the original noise will be cancelled based on sound interference fundamentals. National Instrument's data gaining card is used to analyze the noise signal come from duct by the microphones.[6] Primary signal is analyzed by DAQ card, and then it generates the cancellation signal based on MATLAB software programs. Cancellation signal is given to the duct through DAQ card by an amplifier and a speaker.

Helmholtz resonators

Helmholtz resonator refers to an acoustical device consisting of a cavity (volume) and a neck (opening) which is not connected to any acoustical system. Since the purpose of a Helmholtz resonator is to offer sound attenuation

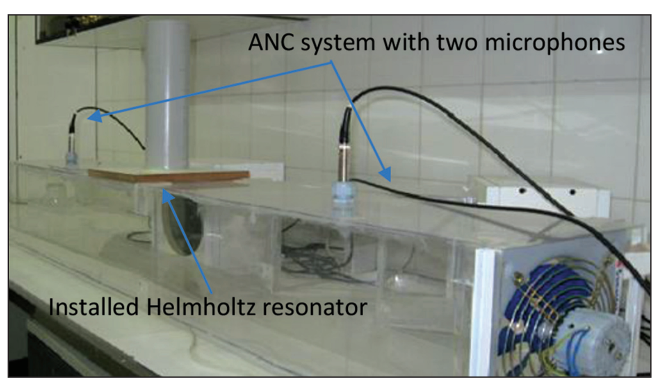

Figure 1: The setup for active noise control and Helmholtz resonator

at a narrow band frequency in proximity to its resonance frequency, it is very important to predict its resonance frequency accurately.

Helmholtz resonator consists of a hollow neck attached to an empty volume. The behavior at the air within the flask is comparable to a driven, damped spring-mass system. Whenever a sinusoidal force acts on air in the flask, the air in the neck will be compared to a mass oscillating on a spring.[7] The air in the cavity serves as the spring and handles and provides the system's stiffness element. Due to its contact with the neck's wall, the mass of air in the neck will experience thermo-viscous losses, and this friction makes a part of the acoustic energy be converted into heat.

RESULTS

Fan generated tonal noise prediction

Due to time limitations, the aim of this paper was to show successful attenuation of 300 Hz tone produced by the fan operating at 220 V by adjacently inserting a Helmholtz resonator into the duct. Prior to conducting the insertion loss experiment, it was necessary to predict the frequency values of the tonal noise and the effectiveness of a Helmholtz resonator designed to drop a special tonal noise produced by a fan within a ventilation duct. These values are given in Table 1.

Tonal noise in ventilation ducts often occurs as a result of an operating fan within the duct. This tonal noise is produced by a periodic disturbance of the fan's inflow or the interaction of the downstream flow with a stationary object. The harmonic frequencies of the propeller fan are shown in Figure 3.

If the noise occurs as a result of the fan's inflow, then the tonal noise can be predicted by the equation:

$$v_n = \frac{nKN}{60}, n = 1, 2, 3... \quad (1)$$

In this equation, v_n is the *n*-harmonic frequency, n is an integer number, K is the number of fan blades, and N is the speed of the fan in revolutions per minute. The resonator's natural frequency is determined by its dimensions and the speed of sound and is described by the equation:

$$v_0 = \frac{c}{2\pi}\sqrt{\frac{S_n}{L'V}} \quad (2)$$

In this equation, v_o is natural frequency, c is the speed of sound in air, S_n is the cross-sectional area of the neck, L' is the effective length from the neck, and V is the volume of the resonator. The production of sound that occurs at resonance leads to more energy loss due to radiation resistance to the opening. Effective length is related to the length from the neck by the equation: $L' = L + 1.4\alpha$, where, α is the radius of the neck's opening of resonator. The effective length accounts for the shape with the opening of the resonator.

It is concluded that the five harmonies might change depending on air temperature, speed of sound in air and applied voltages, DC or AC power.

Pressure antinode prediction

In order for the Helmholtz resonator to be effective within the duct, it was necessary to place the resonator at a location in the duct where there was largest pressure. The tonal noise of interest in this experiment was at 300 Hz. If a speaker were supposed to project a 300 Hz frequency into a duct,

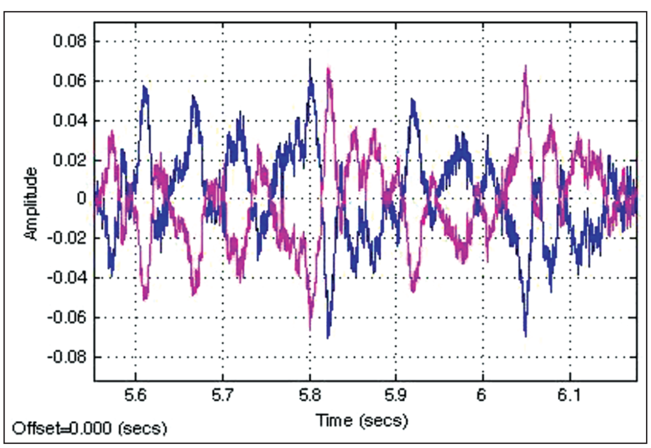

Figure 2: Scope of the running active noise control system on a duct equipped to propeller fan

Figure 3: Designed PVC Helmholtz resonator

Table 1: The specifications of propeller fan

Volts supplied to fan	Fan speed in (rpm)-blades numbers	First harmonic (Hz)	Second harmonic (Hz)	Third harmonic (Hz)	Forth harmonic (Hz)	Fifth harmonic (Hz)
220	2000-8	266	533	800	1066	1333

the speaker's position would be that of greatest pressure and least velocity [Figure 4].

One would expect the highest pressure to occur at integer multiples of half the tone's wavelengths from the speaker:

$$P_{max} = \frac{1.14n}{2}, n = 1, 2, 3\ldots \quad (3)$$

A prediction of the duct's pressure as an act of position for the first 114 cm of the duct can be viewed in Figure 5.

Transmission loss prediction

Although it was impossible to decide the insertion loss due to incorporating a Helmholtz resonator side-branch into a model duct, calculating the transmission loss (TL) due to this insertion loss, allowed as a means to predict the effectiveness of the Helmholtz resonator. One would expect that a large TL would agree to an effective Helmholtz resonator. Because the calculation of TL relies heavily on the dimensions of the Helmholtz resonator, the goal of each prediction was to optimize the dimensions for greatest TL.

So, MATLAB programs were used to simplify the prediction process by calculating the TL for given dimensions over a range of frequencies.[8]

In this paper, three different Helmholtz resonators in structures were considered. The dimensions of resonators are outlined in Table 2. Figure 6 shows the predicted TL for each Helmholtz resonator using Eq (4). Note that these predictions are based on the assumption that no thermo-viscous losses in the resonator; so, while these predictions may not be exact calculation of the TL, they offer insights about the best and more efficient resonator design in the ventilation duct. Based on Figure 6, it is predicted that the resonator with 1.2 cm-diameter is very efficient at reducing 300 Hz tone, produced by the ventilation fan running at 220 V electrical voltages. Helmholtz resonators can be incorporated into ventilation ducts as side branches to reduce the tonal noise created by fans within the duct. The tonal noise drop can be described by the power transmission coefficient, T_0, which states how much acoustic power is transmitted through the duct. The power transmission coefficient for this band-stop filter is written as:

$$T_0 = \frac{1}{1+\left(\dfrac{c/2S_d}{\omega L'/S_n - c^2/\omega V}\right)^2} \quad (4)$$

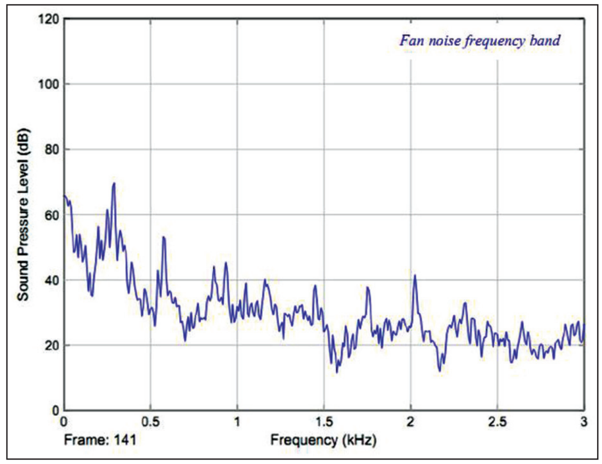

Figure 4: The harmonic frequencies of propeller fan

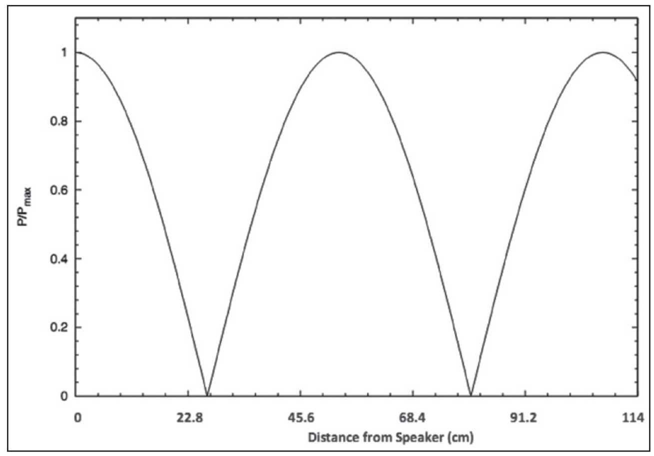

Figure 5: Predicted largest pressures along duct

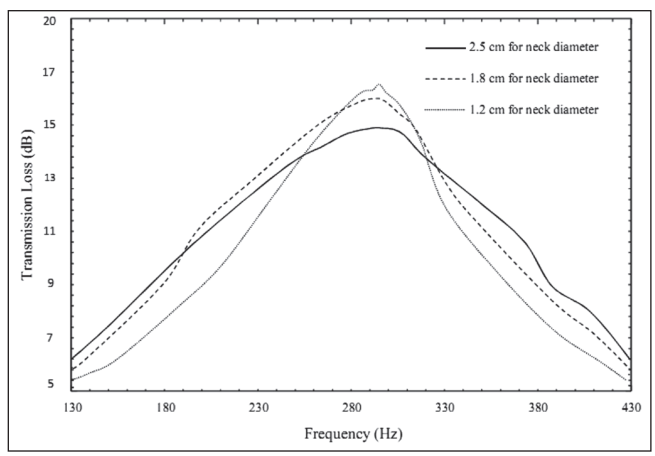

Figure 6: Transmission loss prediction for three different types of Helmholtz resonators

Table 2: The specifications of designed Helmholtz resonator

Neck diameter (cm)	Neck length (cm)	Volume diameter (cm)	Volume height (cm)	Resonance frequency (Hz)	TL
2.5	1.13	7	13.8872	300.00	14.3643
1.8	1.13	7	9.1197	300.00	15.2472
1.2	1.13	7	4.8685	300.00	16.5750

TL: Transmission loss

Here, V is the volume of the cavity; c is the speed of sound, Sd is angle frequency, S_n is the cross-section area at the neck and S_d is the cross-sectional area of the duct. Here the Helmholtz resonator is installed. When $T_0 = 0$, none of the entering acoustical powers are transmitted into the duct. Instead, the incoming acoustical energy enters the resonator and is reflected back toward the source, causing destructive interference. Hence, the predicted TL can be calculated from following equation:

$$TL = 10\log_{10}\left[\frac{1}{T_0}\right] \tag{5}$$

The pressure's values of driven fan noise are measured when tuned Helmholtz installed in a position of 300 Hz frequency noise decreases accurately on the duct. Clearly, according to Figure 7, a cut of 5 dB for a stand-alone Helmholtz absorber tuning to the frequency of 300 Hz can be observed.

The results of noise reduction of a fan by ANC and Helmholtz resonator can be viewed in Figure 8. As it can be seen, the fall of 10 dB is seen due to ANC suitable performance over the frequencies of 100-500 Hz. A great decrease of 10 dB happens in 300 Hz frequency using designed Helmholtz resonator simultaneously when ANC is running.

DISCUSSION

As can be seen from Figure 8, a comparison of noise decline has happened which is presented on the graph with three different colorful lines. Concerning earlier section, for considering tonal frequency noise of 300 Hz, in this part of frequency band, a concentration of control has been done. The blue line shows the value of 10 dB noise cut at the frequency of 300 Hz that is achieved at the first step of using ANC system. Continuing this trend by applying Helmholtz resonator simultaneously has aided the system to reach a fall of 10-12 dB more. Resonance for few frequencies might happen so Geoff Leventhall emphasis on the frequency of 50-150 Hz.[9] The problem in noise control is failure to bring circumstances under control or to keep them for a long time. This case is clearer for ANC systems, especially when you are trying to control noise or vibration of HVAC systems.[10] The present paper, which seeks to find a new way of abatement noise produced by a fan or breeding in a duct, has not succeed to cover a few of defined objects. Thus, for simplicity, this investigation focuses on limiting the tonal noise produced by the return fan at its highest setting.[11] Along with the continuous and intermittent noise criteria, tonal noise must meet the sound pressure level specified by the Narrow-Band Annoyance criteria. According to this need, a single frequency tone must be ten decibels less than the broadband sound pressure level of its octave band. If tonal noise created by ventilation fans is higher than the accepted sound pressure level set by these criteria, then these ventilation systems may pose serious hazards to the health and safety of the crew. This paper aims at minimizing tonal noise produced by fans in ventilation ductwork by incorporating Helmholtz resonators as side-branches to the duct.

As a result, first to design a Helmholtz resonator to attenuate tonal noise produced by a fan in a duct, it should be properly placed on the duct to have the greatest attenuation to a pressure antinode (or greatest pressure) of the duct. Second, tuning the Helmholtz resonator precisely allows a greatest attenuation. One must also consider that the acoustic waves produced by the fan are not constant such as plane waves those produced by a speaker. So, the TL in a duct driven by the speaker is not enough for the TL in a duct driven by a fan. Although the best TL based on Table 2 is equal to 16.5 dB, practically, a discount of 5 dB was the best result of designed Helmholtz resonator. The positive point is that the resonator tries to keep this decline of noise at the interest frequency of 300 Hz while ANC is working.

The results obtained describe a suitable method to discount noise propagation in a duct in a certain frequency. This is not proper to control a wide range of frequency even for the

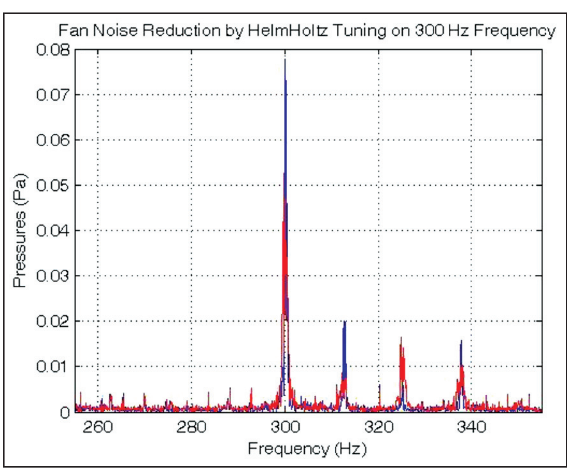

Figure 7: Measured sound pressures of Helmholtz resonator

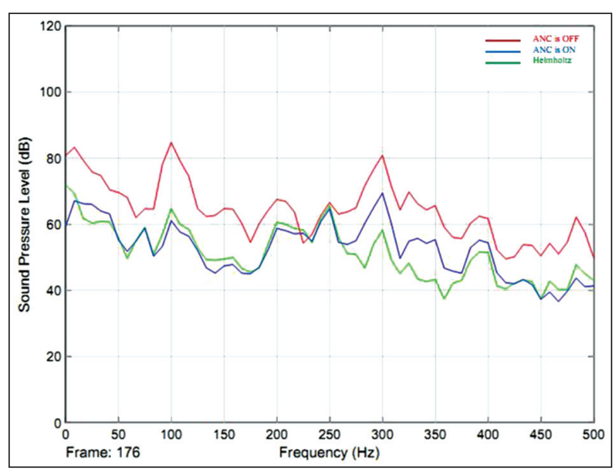

Figure 8: Noise reduction of a fan by using active noise control system and Helmholtz resonator simultaneously

low-frequency band. The suggestion is using ANC action for reduction of noise in a certain part of frequencies, especially low-frequency noise band. The resonator will install to decline residual noise of the peak frequency of the earlier process. However, such study can help scholars to understand better ways of fan or duct noise control in places where silent is the most important issue.

Future works can explore other prediction methods and suggestions to create more attenuation at 300 Hz frequency or other effected frequencies by active noise simulation. The most objects for the future researches can be applying with more numbers of Helmholtz absorber to pick up the residual frequencies of poor performance of the ANC.

CONCLUSIONS

From noise reduction approach, the use of resonator for a certain frequency might be suitable. Nevertheless, in practice, applying this with active noise process simultaneously did not show clear results due to instability active system. However, using a powerful and complete system has been suggested so that a constant energy flow appears. In this case, the Helmholtz resonator acts at the best its activity point.

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