An Experimental Study of the Influence of the Herschel-QuincleTube Length on Noise Attenuation

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Abstract:

The present study addresses experimental results to investigate the effect of the Herschel-Quincke (HQ) tube length on the reduction of noise. In this paper the detailed experiment is carried out in an acoustically cylindrical duct with and without HQ induced by a loudspeaker at various frequencies. Microphone system has been used to measure the net acoustic power transmission in the duct downstream with HQ tube and compared in the duct without the HQ tube. The acoustic wave signal is traveling in the *duct as a plane wave; this wave is generated by a signal generating system with a known sinusoidal wave (sine wave). The microphone is located just after the HQ tube in the duct. In this paper two types of HQ tube have been studied, short HQ tube and long HQ tube. Labview software has been applied for data acquisition, monitoring and analysis. The analysis is done on the basis of time, history and power spectrum.This study makes an exhaustive understanding of power spectrum of two acoustic channels in the duct with and without HQ tube. The results show that there is a great potential for HQ tube system to attenuate the noise over cylindrical duct section. Results showed that, the effective reduction of noise was in the low frequencies range when long HQ tube is used, compared with short HQ tube, the reduction of noise was in high range of frequencies. That means the length of the HQ tube is very important for a passive control of the noise reduction in an industrial and turbofan engines applications.*

***Keywords**: Acoustic, passive control, power spectrum, and HQ tube.*

1.Introduction:

Passive control techniques have been widely used to reduce the noise in industrial and engine systems, such as heating system, gas-turbinegenerators, exhaust stacks and turbofan engines. Their application typically involves modifications to the system hardware to eliminate the source of noise. One of technique used to reduce the noise by using the passive control system is a Herschel-Quincke (HQ).

In this type of passive control device the acoustic wave propagation through a combination of acoustic filter or muffler elements, it has been studied for a very long time in the history of acoustic filters. In the 19th century, Herschel and Quincke [1, 2] study of two tubes in parallel connection, for varying lengths and cross-sectional areas (called HQ tube). They predicted that the cancellation of sound would occur at certain path length differences between the combined signals. In the early 20th century, Stewart et al.[3] refined this prediction. Later, Selamat, et al.[4] extend the work of Stewart by driving a model without limitations on the duct cross sectional. Selamat, et al.[5-8] continued to develop the analysis of the HQ tube.

A Herschel-Quincke (HQ) tube [9] is essentially a hollow side-tube that travels along a main-duct axis and attaches to the main-duct at each of the two ends of the tube. In general, an incident plane-wave acoustic wave, traveling to the right, encounters a branch in the path at the first intersection of the side-tube and main-duct, named the inlet of the HQ tube.

The incident wave divides and will later recombine at the second intersection of the side-tube and main-duct, similarly named the outlet of the HQ tube. A difference in path length will create a phase shift between the recombined signals and consequently attenuation of sound will occur at a number of discrete frequencies. Changing tube parameters such as length, and the distance between inlet and outlet openings, termed the interface distance, the frequencies of cancellation can be adjusted.

The HQ concept as applied to a turbofan engine inlet is illustrated in Figure (1), where a single circumferential array of HQ tubes is positioned on an engine inlet. The case of a single HQ tube for the control of plane wave control is illustrated. Simplistic explanation of the noise cancellation observed with the HQ tube in the case of the plane wave is that some of the sound energy traveling in the main-duct goes into the HQ tube at its entrance, travels through the tube, and recombines with the remaining energy traveling through the main-duct at the exit of the tube. Since the sound in the tube has traveled a larger distance, frequencies exist where the sound in the tube exit is out-of-phase with the sound in the main-duct and would therefore cancel at those frequencies.[10]

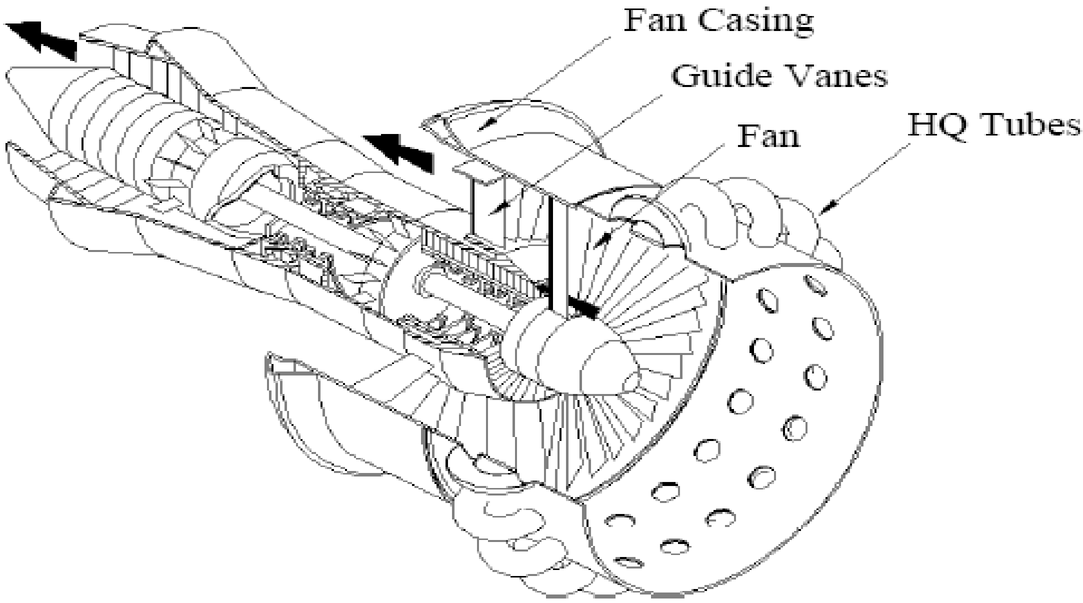

Figure (1) schematic of the Herschel-Quincke tube concept applied to the inlet of a turbofan engine.

Jerome et al. (2002) [11] experimentally investigate both fixed and adaptive HQ-systems for useful reduction of turbofan inlet noise with realistic component son a running Turbofan engine. The Herschel-Quincke (HQ) tube concept is a developing technique that consists of installing circumferential arrays of HQ tubes around the inlet of a turbofan engine.

In this paper; experimentally study the effect HQ tube length on the reduction of the noise in exited duct.

Experimental setup:

In this paper: the structure of the experimental apparatus is shown in Fig. 2. Basically, the rig consists of a cylindrical duct with and without HQ tube, a signal generator system, and a microphone system. The cylindrical duct is an open-open end, with a wall thickness of 0.25 cm, and has a length and inner diameter of 107 cm and 20 cm respectively.

The duct is closed at the end by a loudspeaker, which has a vibrating diaphragm, and the other end is open to the atmosphere. There are two types of HQ tubes mounted on the side of the duct, in the first; is a short HQ tube with a length of 14 cm, and its diameter of 4cm. Tube is fixed at 59cm from the loudspeaker as shown the Figure2. The other; is the long HQ tube with length of 72cm, and with a diameter of 4cm, this type of HQ is fixed at 31 cm from the loudspeaker. The duct is acoustically excited by a signal generating system includes a signal generator, an amplifier, and a loudspeaker. The amplitude of the supply voltage for the signal generator can be varied between 0 and 15 volts by using the amplifier. The rear side of the speaker diaphragm is mounted on an enclosure box is located at the end of the duct, the back side of the loudspeaker should isolated from the front end of the duct, a small air leak is provided in the box, so that changes in the atmospheric pressure do not displace the natural position of the diaphragm, the loudspeaker has a maximum power of 350 W and a frequency range from 20 Hz to 4000 Hz. In this paper; sinusoidal signal mode has been selected.The *rms* pressure is measured using a microphone system, where the microphone islocated just after the HQ tube, as shown in Figure 1, to gain captured signal by microphone, a pre-amplifier have been used.National Instrument DAQ card and Labview software have been applied for data acquisition, monitoring and analyses.

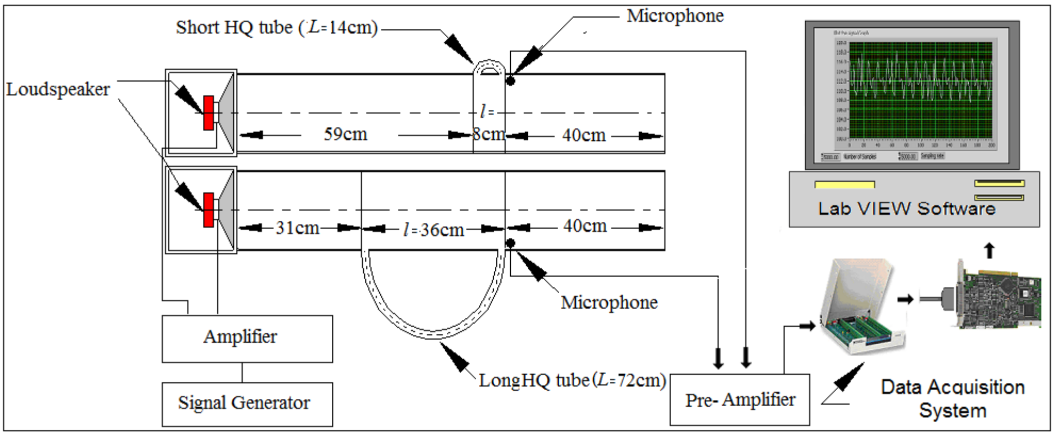

Figure 2. Schematic diagram of the experimental setup.

Results and Discussions:

The noise control devices have been widely used, for Active and Passive control of sound from various types of structures. In this paper; an experimental work has been done on a passive noise control device. The common type of passive control devices is HQ, these technique have been widely used for Industrial noise and turbofan engine noise control. Two test rigs are examined in this paper. In the first test rig, measurements were carried out for short HQ technique installed on a cylindrical duct excited acoustically. In the second test rig;HQ technique with a longer tube installed on the same of the first rigwere extensively studied.

The experiments have been repeated many times and shown to be repeatable. The quite place is required to avoid any external noise effect. The acoustic pressure fluctuation is measured using a microphone system.The voltage applied to the loudspeaker is constant for all experiment at 10 volts. The duct section with diameter of 20 cm is used and the HQ is placed 59 cm form closed duct end by a loudspeaker, the other end is opened to the atmosphere and the microphone is located at just after the end of the HQ tube.

By using the data acquisition system, the digital signal generator is connected to the loudspeaker through a digital to analogue (D/A) and the signal picked up by the microphone, which is connected to the data acquisition system through the analogue to digital (A/D) channel. Sinusoidal signal with various frequencies are generated by signal generator, which is excited through cylindrical duct with and without HQ, The signals are rigorously analyzed by using LabView software. The analysis is done on the basis of time history and power spectrum. The sampling rate is 44100 samples per second and the duration of each sampling is 0.45 second. (Number of samples is 20,000).

The excitation frequency applied was varied from 20 Hz, which is the lowest frequency response of the loudspeaker, to 3 kHz with an increment of 20 Hz. Figure 3, presents a full scanning of the acoustic field in terms of *rms* pressure in volts as a function of excitation frequency with and without short HQ tube, its dimensions;L =14cm, l =8cm, d=4cm, as showed in the experimental setup section. From the results, the effect of the short HQ on the noise level was in the range frequencies between 2300 to 2600 Hz.

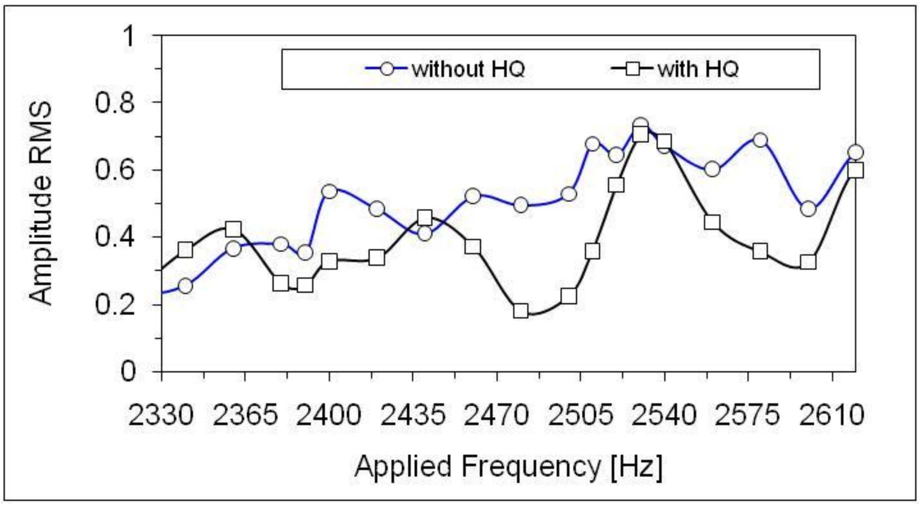

Figure 3. The rms acoustic pressure as a function of the excitation frequency with and without short HQ tube. (Figure is zoom in at the effective range)

It can be seen from the figure that, the maximum reduction was occurred at frequencies of 2380 Hz, 2480 Hz and 2580Hz, in these frequencies the time history of the signals and the power spectrum have been calculated with and without HQ.

Figures4, 5, and 6 show the time history of the signals with and without HQ picked up by the microphone system. Results show that the both signals have a sinusoidal form, but with HQ the signal is less in amplitude.

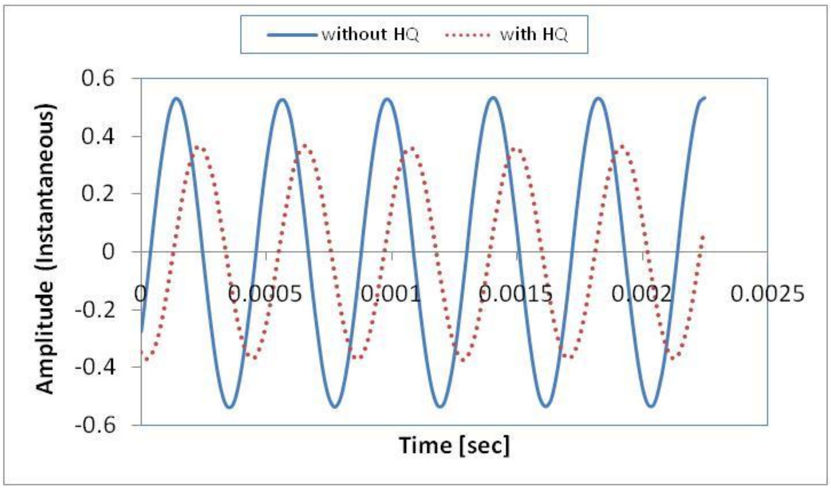

Figure 4. Time history of the acoustic signals, without and with a short HQ at frequency of 2380 Hz.

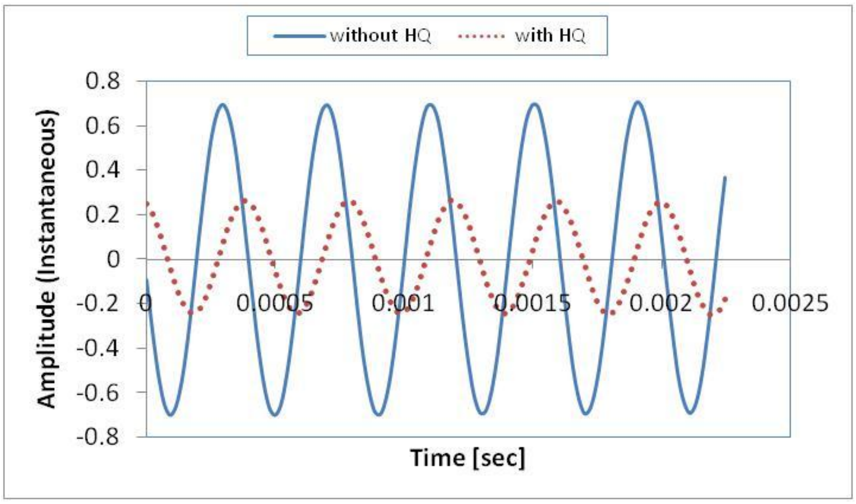

Figure 5. Time history of the acoustic signals, without and with a short HQ at frequency of 2480 Hz.

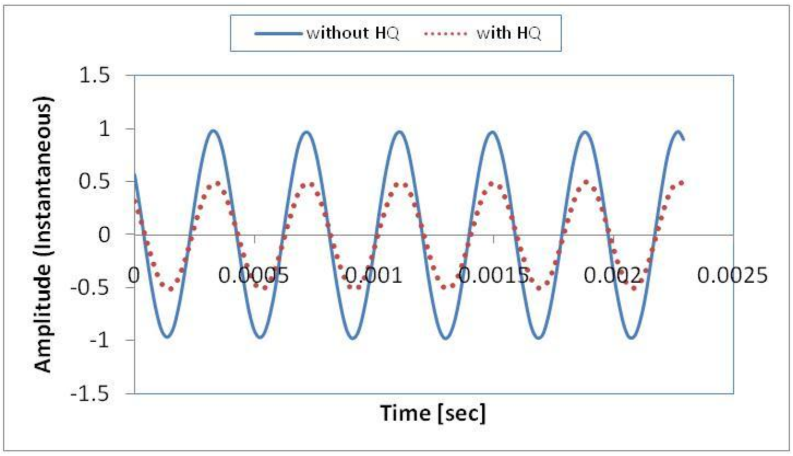

Figure 6. Time history of the acoustic signals, without and with a short HQ at frequency of 2580 Hz.

Figures 7, 8, and 9 show the power spectrum at the applied frequencies of 2380 Hz, 2480Hz, and 2580 Hz. Results show that, only one peak at the same applied frequencies of signal generator, and also here less amplitude of power spectrum with HQ tube, that means the signals are very pure signal and with reduction in noise by using the HQ technique.

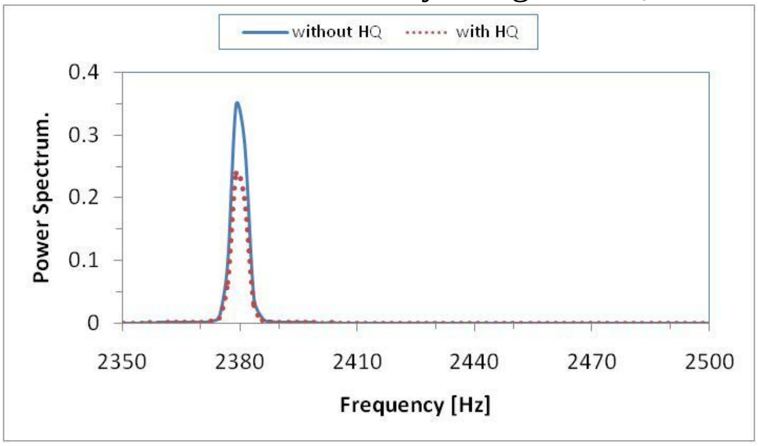

Figure 7. the power spectrum of the signal at the applied frequency of 2380 Hz with and without HQ.

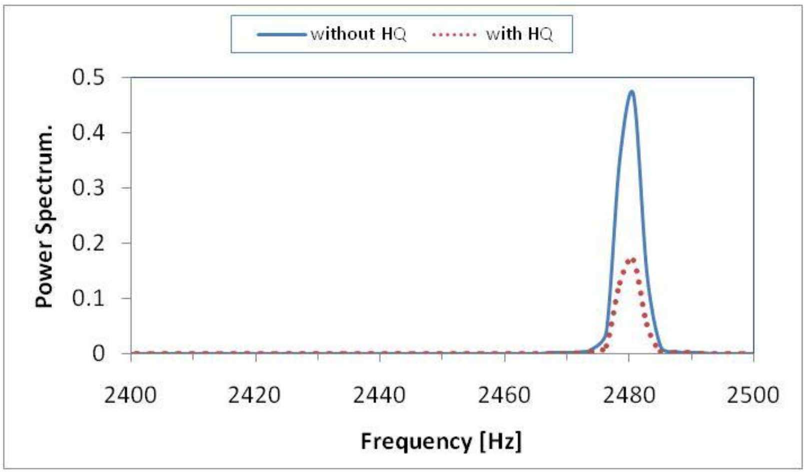

Figure 8. the power spectrum of the signal at the applied frequency of 2480 Hz with and without HQ.

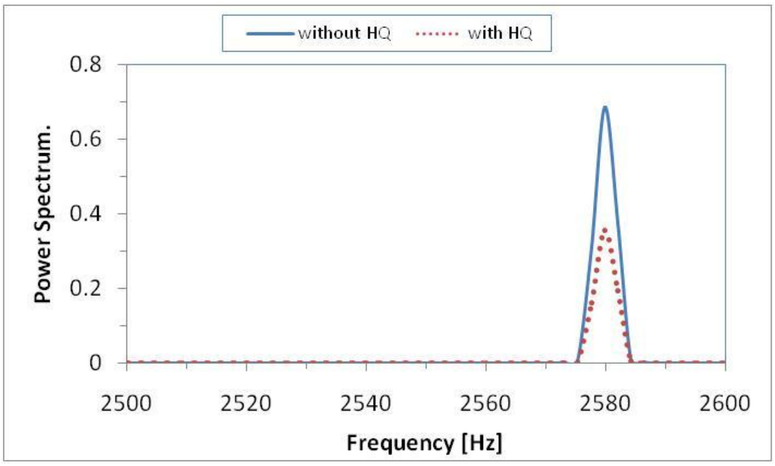

Figure 9. the power spectrum of the signal at the applied frequency of 2580 Hz with and without HQ.

Figure 10. shows full scanning of the RMS acoustic pressure as a function of excitation frequency without and with long HQ tube, its dimensions;*L* = 72 cm, *l* =36 and *d* = 4 cm, as mentioned in the experimental setup section. Results showed that, the effective reduction of noise was in the low frequencies range, with this specification of HQ tube, the reduction wasin the range from 200 Hz to 300 Hz, compared with a short HQ tube is very low. That mean the length of the HQ tube is very important to control the reduction of noise. In second rig of HQ, the lowest reduction of noise was occurred at frequency of 250 Hz, time history and the power spectrum of the frequency are shown the Figure 11 and 12.

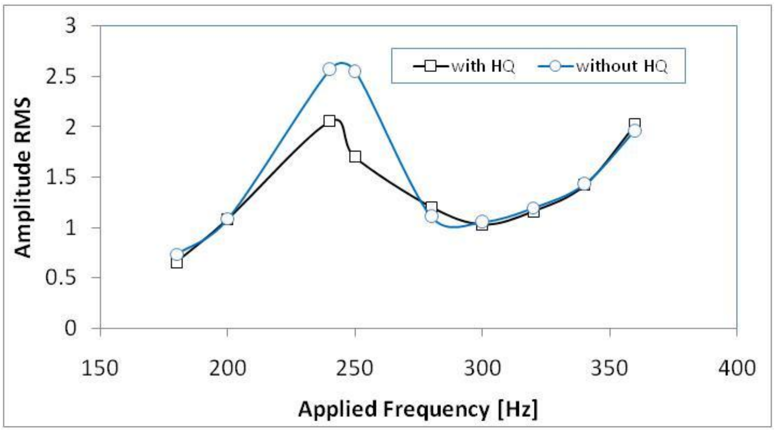

Figure 10. The *rms* acoustic pressure as a function of the excitation frequency, with and without for a long HQ tube. (Figure is zoom in at the effective range)

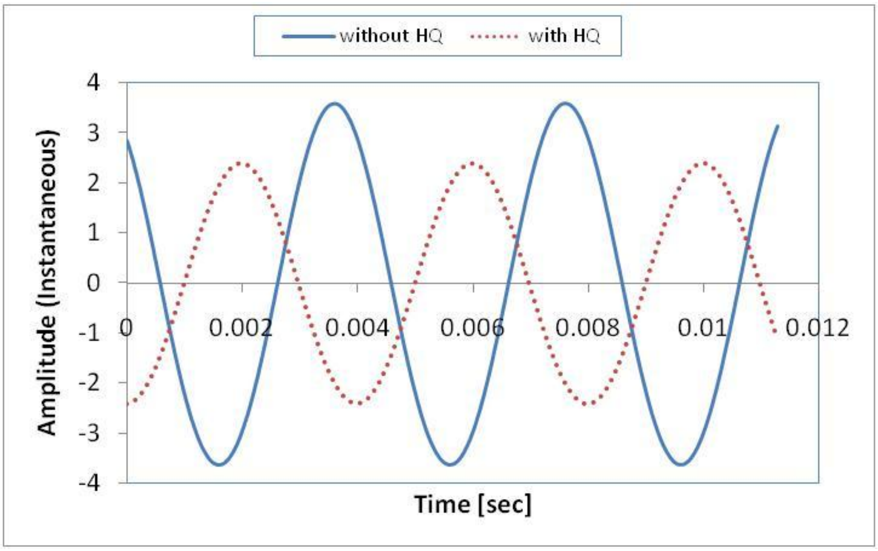

Figure 11. Time history of the acoustic signals, without and with a long HQ at frequency of 250 Hz.

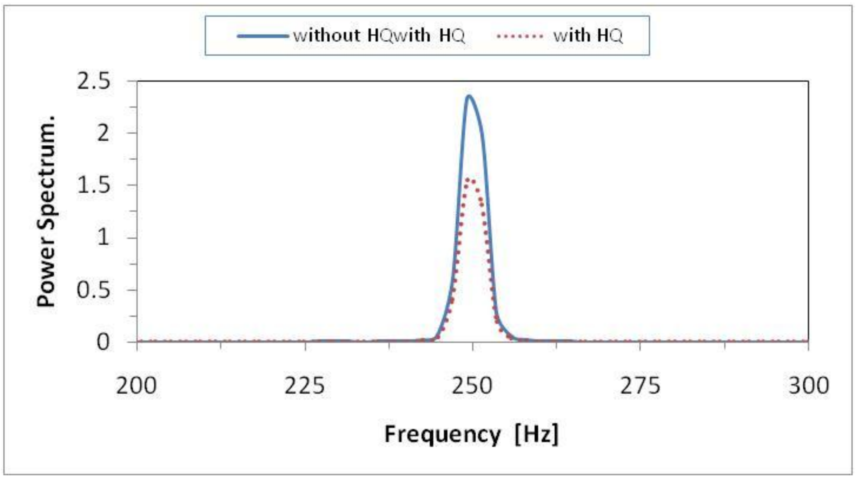

Figure 12. Power spectrum of the signal at the applied frequency of 250 Hz without and with a longHQ.

Conclusions:

The present study describes an experimental work to investigate the effects of the HQ tube length on the noise. The experimental results clearly show that the cylindrical duct section of 20 cm diameter, when the short HQ tube is placed 59 cm from the loudspeaker with a length of 14 cm has the strong effectreduction of noise at high frequency range.

In this type of HQ tube the reduction of noise occurred in the range from 2300 to 2600 Hz, the maximum attenuation percentage of *rms*pressure was 60% at frequency of 2480 Hz compared with a long tube placed at 31 cm from the loudspeaker with length of 72 cm. The reduction was occurred at low range of frequencies (200Hz to 300Hz). The maximum take place at frequency of 250 Hz, with a reduction percentage of 33%. In this paper; it has been concluded that the length of the QH tube plays a significant role in noise reduction and control, for low frequency the long tube should be used to attenuate the noise, and short HQ tube for high frequency.

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