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IMPLEMENTATION OF A SEMI-ACTIVE NOISE CONTROL SYSTEM FOR DUCT APPLICATIONS

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Abstract

Active noise control is becoming a major noise reduction strategy, specially when dealing with one-dimensional propagation as in ducts for instance. Nevertheless it imposes very stringent restrictions on the processing capabilities of the control system. An alternative approach is the use of semi-active control systems. The article presents the design and implementation of a semi-active noise control system for ducts based on Helmholtz resonators. The control system actively tunes the passive, dynamical, absorbing characteristics of a Helmhotz resonator by varying its parameters like the resonator volume through a computer controlled mechanism. The practical implementation of the system as an experimental setup is discussed together with the processing characteristics needed for the system.

INTRODUCTION

The introduction of new products in different branches faces now an ever growing challenge of noise reduction. Not only an overall noise reduction is being targeted but the actual goal of the acoustical development is related to the so called *Sound Quality*. This sound impression is oft used by customers as a *measure* of the quality of the product itself.

Active control of noise sources is becoming an attractive approach for noise reduction. Nevertheless, to actively influence the sound field on a global way, specially in three-dimensional problems but even for unidimensional propagation as in ducts, requires a great amount of computational effort and eventually energy. The semi-active approach here utilized, for noise control in ducts, takes advantage of the, passive, filter characteristics of Helmholtz resonators through a computer system which actively tunes the resonator´s frequency[1].

By the use of several resonators in parallel and different control laws for each of them, one is able not only to reduce the overall noise level emitted but can deliberately interfere in the psycoacoustical characteristics of the sound.

SEMI-ACTIVE CONTROL SYSTEM BASED ON HELMHOTZ RESONATORS

A Helmholtz Resonator connects a volume V to the duct by a neck of length L and cross section S. It acts as a band-pass filter [3] which can be tuned to a specific frequency range by varying those parameters.

The transmission loss of the resonator can be determined, equation (1), as:

$$TL_H = 10\log\left(1 + \frac{c^2}{4S_d^2\left(\frac{\left(1.5\frac{d}{2}+L\right)\omega}{S} - \frac{c^2}{\omega V}\right)^2}\right) \tag{1}$$

where the length L of the neck is corrected by an empirical term with d, representing the diameter of the neck and S_d is the cross section of the duct. Equation (1) is valid if viscosity effects and sound absorption inside the resonator are neglected and do not consider higher resonant modes [4][6]. An experimental validation of equation (1) for the specific case of the duct and resonator presented is shown in [5].

The frequency ω_0 at which the resonator is tuned can be calculated making the denominator in equation (1) vanish. This gives:

$$\omega_0 = c\sqrt{\frac{S}{\left(1.5\frac{d}{2}+L\right)V}} \tag{2}$$

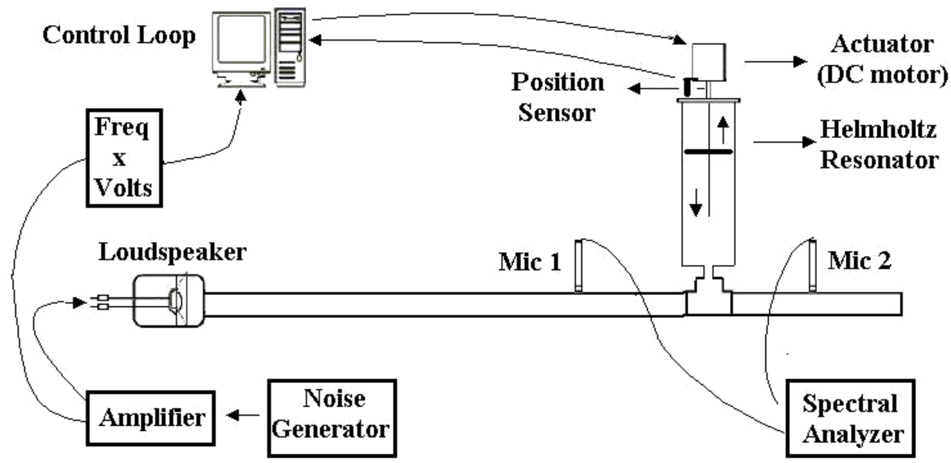

Figure 1: Scheme of the semi-active noise control in a duct.

In the semi-active noise control, shown in figure 1, the main frequency component of the noise inside de duct is assessed, either digitally by means of a frequency analysis of the signal from a microphone or by an electronic circuit converting the frequency content of the signal in a proportional electric voltage. Once this main component is known, equation (2) is used in a control loop to change, for instance, the resonator volume V, in order to absorb this main frequency.

The main difference to an active control system is that no acoustic energy is actively fed up into the duct. Only the passive absorption of the resonator is used to reduce the noise. Nevertheless, since the passive characteristics is actively tuned by the control loop, a semi-active control system is built.

EXPERIMENTAL SETUP

The previous section introduced the concept of the active variation of the characteristics of the Helmholtz resonator. The experimental implementation of this concept is achieved through a computer controlled resonator, which can have its volume varied by an electric actuator. This experimental setup is shown in figure 2.

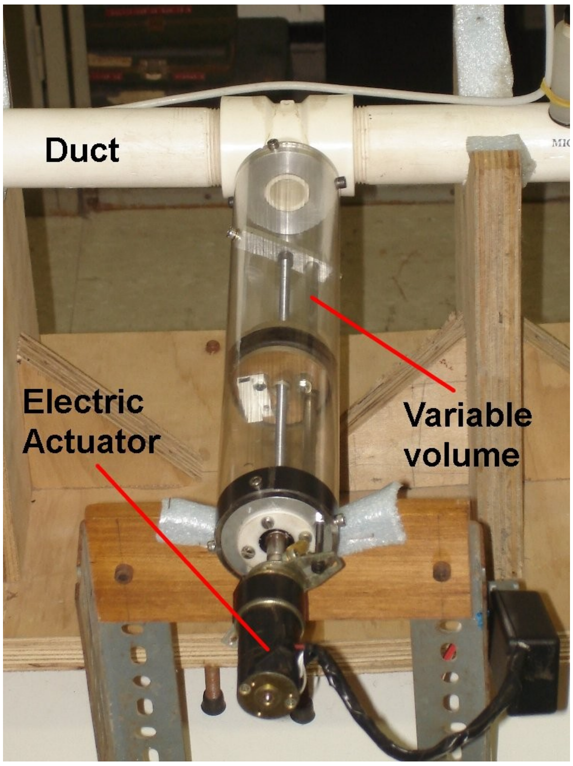

Figure 2: Computer controlled resonator of the semi-active noise control system.

The prototype uses a frequency to voltage converter and a digital-to-analog converter board to identify the noise inside the duct. An electric motor with reducing gears moves a piston, through a spindle, varying the active volume of the resonator.

The software implementing the control loop in the computer uses a pulse sensor to count the turns of the spindle, positioning the piston according to equation (2), in order to absorb the main frequency component of the noise in the duct. Figure 3 shows an overall view of the experimental setup, including the duct with a loudspeaker at its left end, acting as noise source, microphones used to evaluate the sound pressure inside the duct and the computer used in the control loop.

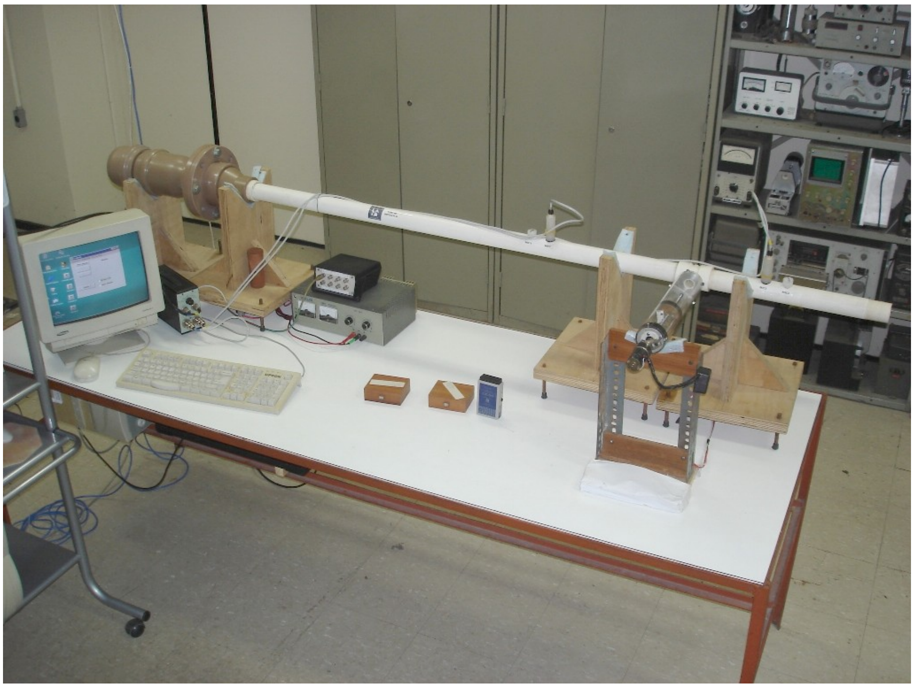

Figure 3: Overall view of the experimental setup.

This experimental setup is used to measure the transfer function between two microphones, after and before the resonator, to demonstrate the function of the semi-active control system.

The diameter of the duct and resonator are 40mm and 57mm respectively. The resonator neck is 34mm long with an internal diameter of 20mm. It can be tuned, through the piston positioning, to frequencies ranging, approximately, from 150Hz to 300Hz. Microphones are positioned at 1060mm and 1430mm from the noise source. The overall length of the tube is 1885mm. The equipment used in the set-up, which can be partially seen in figure 3, are listed in table 1:

Table 1: Instrumentation.

Capacitive Microphones	Bruel & Kjäer model 4165
Microphone Power Supply	Bruel & Kjäer model 2807
Frequency Analyzer	DataPhysic SignalCalc Mobilyzer
Acoustic Calibrator	Larson Davis CAL200
Impedance Tube as duct	40mm internal diameter
Source	PC-CreativeLabs Soundboard, Power Amplifier and 4” Loudspeaker

RESULTS

The function and the attenuation obtained by the use of the semi-active noise control based on the Helmholtz resonator is assessed by measuring the transfer function between the microphones [2]. Although the measurement of the transmission loss of the resonator would give a better indicator of the performance of the noise control system, the transfer function is measured for a later use as filter characteristics in designing a control law to generate a desired output noise from the duct if the input noise is known in advance.

The actuator of the spindle has a limited speed, limiting the frequency variation in time which the system is capable to follow. The system must tune the resonator by moving its piston from a position ***A***, tuned to frequency f_A, to another position ***B***, tuned to frequency, f_B, what takes some time. In order to evaluate the behavior of the system the frequency response for the interval 150Hz to 300Hz is obtained experimentally through linear frequency sweeps. The signals of the microphones are digitally processed allowing the determination of the transfer function $H_{12}(f)$, expressed in dB:

$$H_{12}(f) = 10\log\left(\frac{S_{12}(f)}{S_{11}(f)}\right) \quad (3)$$

where the terms $S_{11}(f)$, $S_{22}(f)$, $S_{12}(f)$ and $S_{21}(f)$ represent the auto- and cross-spectra of the microphone signals1 and 2 respectively.

To compare the results with the situation with no resonator at all and with the resonator statically tuned to a specific frequency, similar measurements are done for those situations. The results are shown in figure 4 below.

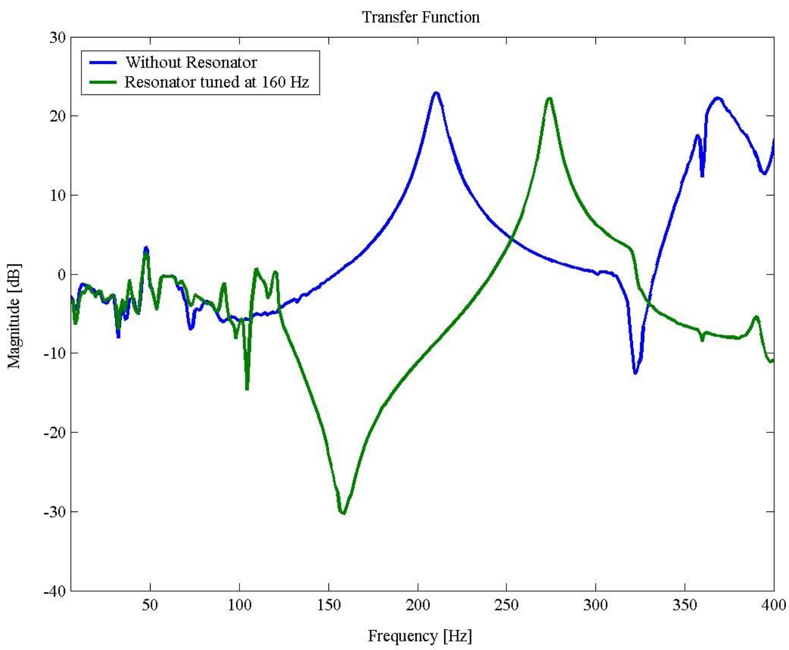

Figure 4: Transfer Function $H_{12}(f)$ for no resonator in the duct, and for resonator tuned to 160Hz.

Since the sweep ranges from 150Hz to 300Hz the portion of the graphic outside this limits is of no interest. An important point regarding the dynamics of the actuator is related to the sweep speed. Since the control system, when turned on, must follow the sweep, a sweep time of 12 seconds would correspond to the actual speed of the piston to travel from its extreme positions, representing the tuning from 150Hz to 300Hz. Sweep speeds below this limit, i.e. Sweep times higher than 12s, will allow the piston to follow the instantaneous excitation frequency.

The behavior of the system, in this situation, can be seen in figure 5 for the curves for sweeps of 18s and 24s. Figure 5 also shows the results for faster sweep rates, 9s and 12s, which are faster than the piston can follow, and on the limit, respectively. The degradation on the attenuation can be seen around 250Hz and above. In all measurements the piston started to follow the sweep from the 150Hz position. If it would start from the 300Hz position the effect would have been seen on the lower frequency side of graphic. For the sake of comparison the transfer function for the case of no resonator in the duct is shown in the same figure.

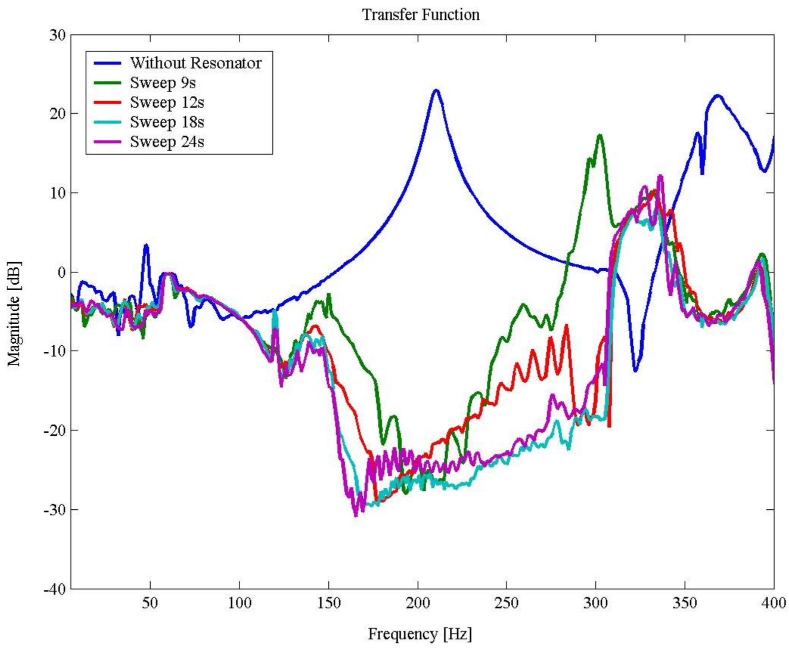

Figure 5: Transfer Function $H_{12}(f)$ for different sweep scan times.

Figure 6 shows clearly the attenuation obtained by the active tuning of the resonator, comparing the results obtained for no resonator, fixed tuned resonator and semi-active system.

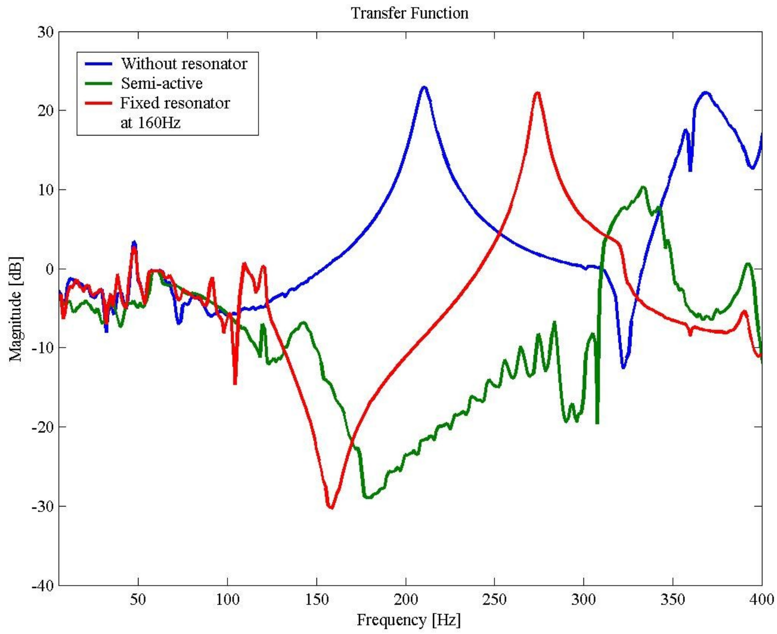

Figure 6: Comparison showing the effect of the semi-active noise control system.

CONCLUSIONS

The paper shows the experimental implementation of a semi-active noise control system based on the active variation of the volume of a Helmholtz resonator. The passive filter characteristics of the resonator is tuned to specific frequency components of the noise inside a duct.

The behavior of the system is largely influenced by the dynamics of the chosen actuator. If the main frequency component of the noise is varying more rapidly than the actuator is able to make the piston follow, the noise control system will not operate in a useful way.

The use of the control loop to actively tune the resonator enables the noise reduction to be extended to a broader frequency range when compared to the static resonator. The frequency range is related to geometrical properties.

The use of the semi-active control system can reduce the noise in ducts from ventilation systems or air-conditioning, and from engine exhaust systems. The sound quality aspects of the noise emitted by the duct opening can be assessed through the control law and by the operation of two or more resonators, each with its own control.

The system has its patent requested for the application in exhaust systems and HVAC-ducts.

Effects of flow, pressure and temperature inside the duct are subjects of further research.

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