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EXPERIMENTAL STUDY OF A PIEZOELECTRIC DEVICE TO CONTROL THE SOUND ABSORPTION COEFFICIENT

Fabiana Alves Pereira
Energy Efficiency Laboratory, School of Electrical Engineering, Federal University of Uberlândia, Av. João Naves de Ávila, 2121, Uberlândia, MG, 38408-196, Brazil
fabiana.pereira@ufu.br

Israel Jorge Cárdenas Nuñez
Department of Mechanical Engineering, Federal University of Triângulo Mineiro -Av. Dr. Randolfo Borges Junior, 1250, 38064200 - Uberaba, MG - Brazil
israel.nunez@uftm.edu.br

Geisa Arruda Zuffi
Marcus Antonio Viana Duarte
School of Mechanical Engineering, Federal University of Uberlândia, Av. João Naves de Ávila, 2121, Uberlândia, MG, 38408-196, Brazil.
mvduarte@ufu.br, geisazuffi@ufu.br

Abstract. *This work presents a piezoelectric sound absorber that can be applied in many different environments, including cleanroomss. The proposed device aims to improve the sound absorption through the vibrations control of a piezo buzzer coupled to a thin aluminum plate. Several tests were conducted in an impedance tube, under plane wave propagation condition, at frequencies between 200 and 1000 Hz, using a fixed controller implemented in Simulink/Matlab® and a USB-6259 board from National Instruments. The results show the effectiveness of the proposed system for improving the absorption coefficient of the system.*

Keywords: *absorption coefficient, piezoelectric, vibration control*

1. INTRODUCTION

According to a recent research published by the World Health Organization (WHO), around 466 million people have disabling hearing loss. By 2050 it is estimated that this number will be over 900 million, which corresponds to one in every ten people (WHO, 2019).

Among several causes of hearing loss, this work highlights those caused by prolonged exposure to high levels of noise at the workplace, that affects both developing and developed countries (Dahlstrom, 2015).

Hence, one of the industries greatest challenges consists in finding a technology capable of eliminate or reduce noise to acceptable levels, in order to guarantee the health and the well-being of the employees. However, the currently systems available for noise canceling, or reduction, are still very limited from a practical point of view.

Basically, given the financial and operational aspects, the most commonly used noise control methods are those applied to sound transmission, whether using techniques passive or active. Nonetheless, these techniques are not always feasible because they involve expensive systems with a limited control area, or because they are inefficient at lower frequencies and unsuitable for certain environments, such as cleanrooms.

Cleanrooms are controlled environments, equipped with an indoor air quality maintenance system to ensure the introduction, generation, and retention of particles inside the room below the limits specified by the standard (14644-1, 2015). Therefore, in these locations, the application of sound-absorbing materials is impractical, given its porosity nature. And although there are already available acoustic linings and soundproof paints capable of promoting enclosures acoustic treatment, suitable for these sites, none of these methods have a considerable attenuation in low frequencies.

In this context, and considering the material science and engineering progress, efforts have been employed to overcome the limitations of active systems, making feasible the application of Active Noise Control (ANC) techniques in many different environments (Nunez *et al.*, 2019).

An alternative, whose potential has been explored in the ANC researches, consists in the use of new types of materials, such as the piezoelectric ones, to replace the conventional electromagnetic speakers and microphones used in the traditional noise control systems (Rothemund *et al.*, 2018; Mirshekarloo *et al.*, 2018). For example, Mirshekarloo *et al.* (2018) developed a transparent speaker using piezoelectric polymer materials and evaluated the device performance in active noise mitigation for window application with a ventilation function. The results presented by the authors confirm the potentiality of the piezoelectric type speakers.

Kundu and Berry (2011) created an intelligent foam, coupling a polyvinylidene fluoride (PVDF) film to the rear surface of the melamine foam and verified the ability of the proposed device to control the sound absorption coefficient and the transmission loss in an impedance tube, with plane wave propagation, under normal incidence in the frequency range between 100 and 1500 Hz. The results obtained by Kundu and Berry indicate that the proposed smart foam is capable of improving the sound absorption capacity, however, does not offers a significant contribution to the loss control of sound transmission in both low and high frequencies.

Lastly, Bricault *et al.* (2019) in their work utilized a single piezoelectric patch with a negative capacitance shunt for damping the vibration of a thin aluminum square plate and reduce, consequently, the acoustic radiation of the vibrating plate.

Thus, considering the researches mentioned above, the potentiality of piezoelectric materials to create compact systems with a better cost-benefit relationship and the previously obtained numerical results (Pereira and Duarte, 2015), in this work we presented a piezoelectric sound absorber, that can be applied in cleanrooms. The proposed device was evaluated in an impedance tube, under normal incidence, using a fixed controller implemented in Simulink/Matlab® and a data acquisition module NI USB-6259.

2. SOUND ABSORPTION

The sound absorption coefficient of a given material can be obtained experimentally, through the transfer function method as standardized by ISO 10534-2 (1998). In this method, an sample of the material is placed at one of the extremities of the impedance tube and excited by plane waves generated at the opposite extremity. Then, by the complex acoustic transfer function of two microphones located near to the sample, Eq. (1), the normal-incidence complex reflection factor, Eq. (2), and the normal-incidence absorption coefficient, Eq. (3), are calculated in the frequency domain using the following equations.

$$H_{21}(\omega) = \frac{p_2(\omega)}{p_1(\omega)} \tag{1}$$

$$R(\omega) = \frac{H_{21}(\omega) - e^{ikd}}{e^{ikd} - H_{21}(\omega)} e^{2ikL} \tag{2}$$

$$\alpha(\omega) = 1 - |R(\omega)|^2 \tag{3}$$

Where d is the inter-microphone spacing, L is the distance between the piezoelectric sound absorber and the closest microphone and k is the acoustic wavenumber.

3. CONTROL SYSTEM

In this section, will be shown the details of the piezoelectric sound absorber and the physical control system used to implement the active absorption.

3.1 The piezoelectric sound absorber

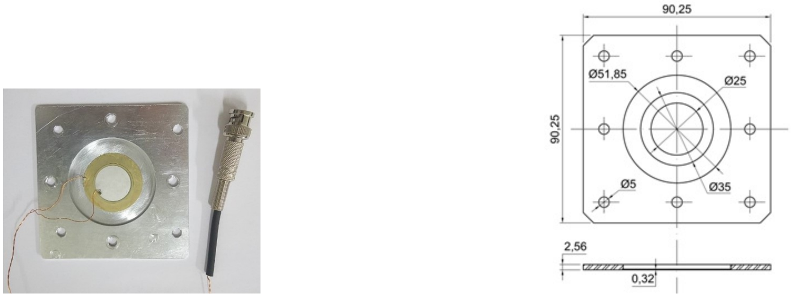
The sound absorption of a material depends on aspects such as frequency, angle of incidence, type of acoustic field, density, thickness and internal structure of the material (Gerges, 1992). Thus, the best sound absorbers are, generally, porous or fibrous materials, since their structure allows the thermal dissipation of the incident energy, by multiple reflections and viscous friction.

However, as previously mentioned, such materials are unsuitable for environments in which airborne particle contamination interferes in the final quality of the process. So, aiming to develop a new control actuator that is suitable for such environments, this work proposes a piezoelectric sound absorber.

The piezoelectric sound absorber consists basically of a cylindrical cavity with a piezoelectric actuator glued in a thin aluminum plate, shown in Fig.1, positioned at on one side and an acoustic foam on the other side. The system was properly designed to be fixed to the extremities of the impedance tube without acoustics leak.

3.2 Experimental setup

In order to verify the potentiality of the proposed device developed to promote sound absorption by controlling the vibration of the piezoelectric actuator, a fixed controller, based on Leroy *et al.* (2011), was applied to an plane wave propagating in an impedance tube. The Fig. 2 shows the experimental setup and the constructed bench.



(a) Device photo (b) Geometric dimensions in mm

Figure 1. Piezoelectric sound absorber.

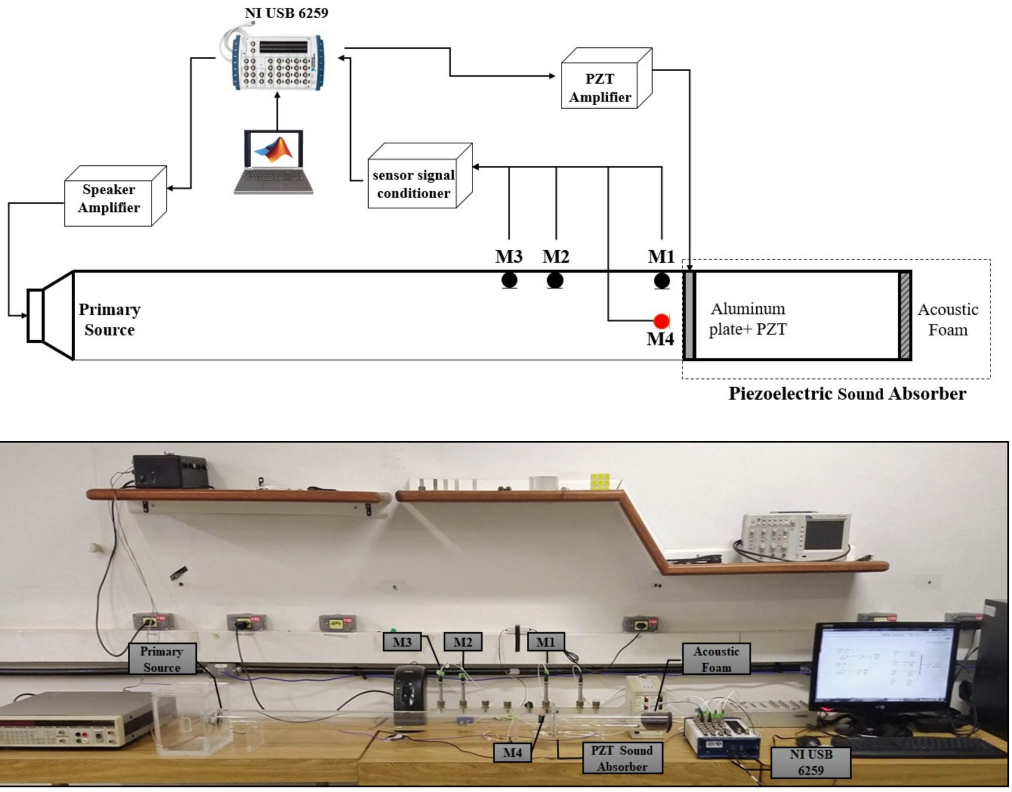


Figure 2. Experimental bench.

The block diagram of the active control strategy applied to improve sound absorption is shown in Fig. 3. In this system, to obtain the control input of the piezoelectric sound absorber that maximizes the absorption coefficient, i.e., that minimizes the reflected wave, was used a electret unidirectional microphone (M4) from Panasonic (WM- 55A) as an error sensor, positioned inside the tube in front of the piezoelectric sound absorber. Thus, mathematically, the residual error signal is given by Eq. 4.

$$e = H_{\mathrm{p}}x + \Gamma H_{\mathrm{s}}x \tag{4}$$

Where Γ is a weighting filter that minimizes the error signal energy (y), given by Eq.5, and H_p, Eq. 6, and H_s, Eq. 7, were the primary and secondary frequency response functions ($FRFs$), obtained by driven the primary source (x) and the piezoelectric sound absorber (u) with white noise . The Fig. 4 shows the $FRFs$ results, using a sampling frequency of 16.393 kHz,

$$\Gamma = -\frac{H_{\mathrm{p}}(\omega)}{H_{\mathrm{s}}(\omega)} \tag{5}$$

$$H_{\mathrm{p}}(\omega) = y/x \tag{6}$$

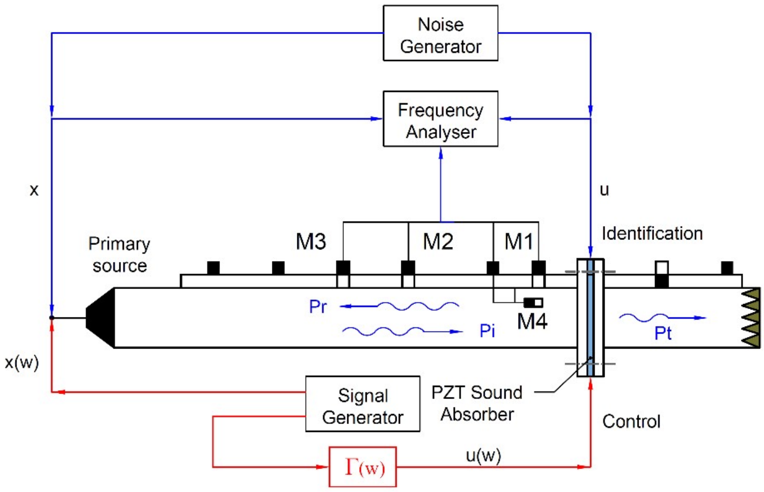


Figure 3. Block diagram of the active noise absorption control strategy.

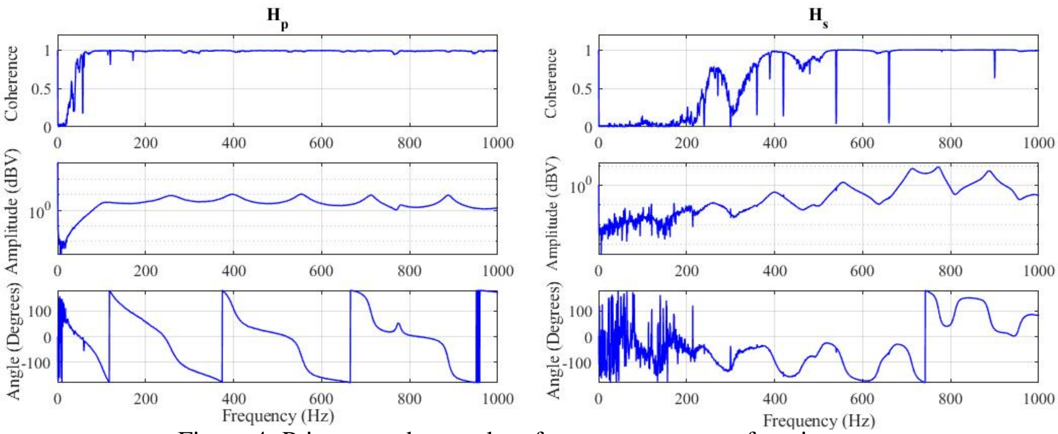


Figure 4. Primary and secondary frequency response functions

$$H_s(\omega) = y/u \tag{7}$$

Therefore, considering a harmonic perturbation of the type

$$x(t) = sen(\omega_n t) \tag{8}$$

The control input is given by

$$u(t) = |\Gamma(\omega_n)| sen(\omega_n t + \Phi(\omega_n)) \tag{9}$$

Where ω_n is the disturbance frequency and Φ is the phase of $\Gamma(\omega_n)$.

Also, in addition to the unidirectional microphone, three free-field microphones PCB model $377B02$ were positioned along the tube for the sound absorption coefficient calculation. The distances between the microphones used in the absorption coefficients calculation (M1, M2, and M3) and at the measurement of the minimum and maximum absorption frequency, are shown in Tab. 1.

Table 1. The microphone pairs used in absorption measurements.

Pair	d(mm)	f_{min}	f_{max}
M1-M2	275	63	498
M1-M3	345	48	397
M2-M3	70	245	1960

4. RESULTS

As exposed in Fig. 4, the piezoelectric actuator responds only to frequencies over $200Hz$. Thus, to test the performance of the piezoelectric sound absorber, several experiments were made with a single frequency disturbance between

200 and $1000Hz$ with a $50Hz$ increment. The results obtained are presented in Fig. 5.

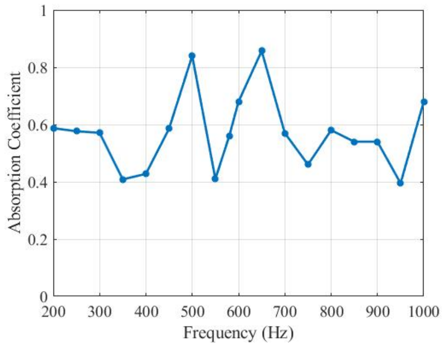


Figure 5. Sound absorption coefficient of piezoelectric sound absorber.

As can be seen in Fig. 5, the absorption coefficient of the proposed device varies from 0.4 to 0.6 in the analyzed frequency range. Since the absorption coefficient of an aluminum plate is almost zero, according to the literature, these values indicate a significant improvement of the sound absorption coefficient.

Moreover, during the experiments, it was observed that the proposed controller is extremely sensitive to changes in the amplitude and/or in the signal phase. Thus, minimal adjustments can significantly improve the system response. For example, in the frequencies of 450 and $650Hz$, a fine-tuning increased the absorber coefficient to approximately 0.8.

Therefore, in future works, it is intended to implement an adaptive controller to tune the control amplitude and phase, aiming to improve the performance of the proposed device.

5. CONCLUSION

In this work, a piezoelectric sound absorber was experimentally evaluated in an impedance tube, using a manual controller implemented in Matlab® and a NI USB 6259 board.

The results obtained shows that the proposed device was able to improve the sound absorption coefficient in an impedance tube, under plane wave propagation condition, at frequencies between 200 and $1000Hz$, where traditional methods are inefficient.

However, for this proposed device to be viable, it is still necessary to improve their response, either through the use of adaptive time-domain control techniques or through structural absorber optimization, what is intended to future works.

6. ACKNOWLEDGEMENTS

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