23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

PZT AND PVDF USED IN CONTROL OF VIBRATION AND NOISE SOUND

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Abstract. *The piezoelectric materials is a class of dielectric structures that exhibit deformation material in response to application of an electric charge and emit dielectric charge in response to mechanical deformation in material. These materials can be used important components of active control in determination of strain or deformation (in effect sensor) as well as structural mode in action controller (in effect actuator). They are widely used in system control in detection and suppression of vibration. They have useful advantages to the piezoelectric elements in vibration control and in audible noise control, because he uses minimum space of structure. The variation of strain tensor to the piezo ceramic in action of a constant load is less than 12% for temperatures up to 120 º C. Naturally the PZTs it had good stiffness and when glued in the structure incorporates the resistance of structure, resulting in an excellent conversion of electrical energy in mechanical energy. Piezo ceramic materials although it has advantageous in many applications even have molding difficulties incomplex shapes due your fragility and brittle. One option is the use of PVDF film which having the consistency of a plastic sheet and can be affixed virtually in any geometry, it has high sensitivity and accuracy measurements and thus it can be uses as sensors. This work aims theoretical and experimental study to the characteristics of PZT and PVDF films acting as sensors and actuators in mechanical vibrations. With your use in vibration control and the consequences in the structure.*

Keywords: *PZT, PVDF, Active Control, Controllers*

1. INTRODUCTION

Among many problems that afflict human society the audible noise is the main factor to be controlled and reduced. The undesired sound known is produced by tools and general machines which can be produced in several environments. The control can be realized by innumerous engineering techniques from the passive features or active means. However this choice depends to the requirement and efficiency technique required. It is discusses differences presented by each technique available pointing advantages and disadvantages. In nowhere days there is an increase the study of active noise technique and this process has shown a satisfactory development. The researches in environment academic or private intensify new concepts, practical and use. The theoretical understand to the variables may affect their performance.

The purpose of this work is makes a comparative theoretical study to the acoustic field inside the ducts trough to experimental measurements. Using active controllers in to employ in reducing of audible noise generated in the structure of ducts.

2. STATE OF ART

Piezoelectric materials is a class of dielectric structures that exhibit a material deformation in response to application of electric field and produce a charge in response to the mechanical deformation in material. These materials can be used as important components of active control by determination of strain or deformation (effect sensor), or in action controller (effect actuator) in structures. They have widely used in control systems by detection and suppression of vibration.

One of the advantages of piezoelectric elements is the use in vibration control and control of audible noise obtained for (Melo, 2004) as well as the location of structural analyzed. The variation in the piezoelectric strain tensor for piezo ceramic materials under the action of constant load is less than 12% in temperatures up to 120º C. Perhaps to the nature of ceramics to the PZTs has a good rigidity and resistance when bonded to the base of structure which results in an excellent conversion of electrical energy into mechanical. Piezo ceramic materials although it has advantageous in many applications would have difficulties in mold complex shapes due to their fragility and brittle. One option is the use of PVDF film, which has consistency of plastic sheet and can be affixed to any geometry, high sensitivity and accuracy in measurements and thus used as sensors. This work studied the characteristics of PZT and PVDF films acting as sensors and actuators in mechanical vibrations.

3. ACTIVE CONTROL OF SIGNAL

Basically consists in take the sound wave at point in the atmosphere and then amplifies and delayed appropriate in injecting into an actuator which will to generate a sound wave in order to cancel the noise environment; as shown in Fig. 1.

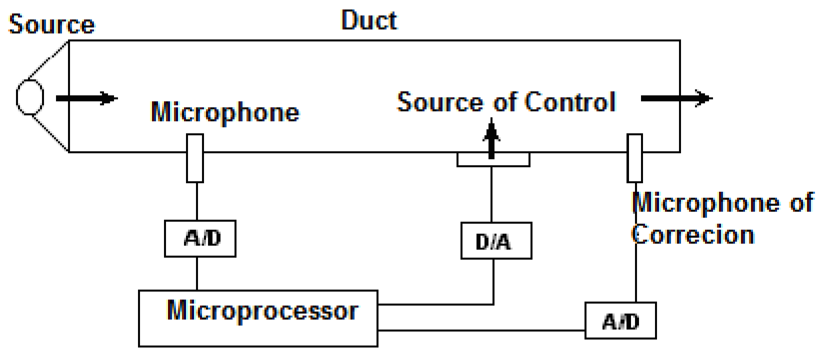

Figure 1 - Mechanism used in typical active system control

The basic idea of this technique is due the physical characteristics inherent to the sound waves, where verify mechanisms to the addition or subtraction of sounds or vibrations. As well as the fact to the electrical signals propagate at higher speed much as to the speed of sound.

This technique requires a substantial understanding the mechanisms of propagation and their variables surround that may have great influences on the desired final efficiency. As concluded by (Alli and Singh, 2000) that addressed the difficulty of establishing numerically the poles and zeros in to the models and those mathematical expressions in formulation to the sound wave equation. Already (Bai and Lin, 1997) compared, three control mechanisms applied in active cancellation of sound in ducts, such as: the feedforward control, feedback control and hybrid control. The use of robust control techniques obtaining results in terms of performance, stability and robustness. According to the author's the choice of the techniques guided and is closely to the level of knowledge the variables that influence the performance and stability where not always easy to read and understand. Now (Cazzolato, 1999) investigated the active noise control in closed structures where there is structural coupling. It was examined alternatives to the conventional microphone and accelerometer. And the study it was made by Statistical Energy Analysis. And (Badawy, 2000) demonstrated that the attenuation of sound is directly proportional to the length, thickness and porosity of the medium and inversely proportional to the resistivity and area of duct.

However, the active control technique offers some advantages and disadvantages second already known (Gerges, 1992); where one can mention that the most significant are:

As advantages we have:

• High attenuation at low frequencies, where other control systems, such as resistive or reactive silencers are not effective.
• The size of the device is greatly reduced.
• They are easy to install, requiring no large physical spaces.
• The system has a stable behavior when it comes to calibration.
• Eases may stand at around 50 dB at discrete frequencies and around 30 dB in sound field broadband frequency.

Among the studies that demonstrate the advantage of the control a material has been produced by (Serrand and Elliott, 2000) which show that the sound control gradually reduces with increase of frequency.

As a disadvantage we have:

• Commitment of the experimental results due to the influence of beeps undesirable compared with values obtained from mathematical model.
• The microphone and speaker to capture field generation must have inverted flat response at low frequencies, which is not easy.
• Because the radiate acoustic speaker both in the source direction as in the opposite direction, generating a sound field that can contaminate the microphone signal.

• The reflections can generate standing waves thus creating problems for the feedback.
• The need for a adaptive data processing system since the signal received varies with the speed.

Already in (Steel and Bernhard, 1993) illustrate the limitations of active control of sound and vibration in most effective in propagation of small regions. Contemplating one of the disadvantages mentioned some work shall starkly in to the use of adaptive algorithms like LMS (Least Mean Squares) in prediction of attenuation or in control itself. In the (Park, 1997) were able attenuations periodic disturbances using LMS algorithm also evidenced by (Kang and Kim, 1997) and (Wang and Ren, 1999). And (Sohn with Lee, 2000) conducted studies about a controller separates the possible tonal components in sound signal creating an anti-noise to a specific signal noise, even as (Kim and Kim, 1994) describe a control system which suppresses sound waves whose modes are strongly influenced by using adaptive systems as tools. In general, there are three basic types of active controls which are named in according to given the capture of reference signal, by: control of feedforward, the feedback control and hybrid control.

3.1 Variables Influencing the Voltage Electric Generated in the Piezo Structure

It is presented here the mathematical equations formulated by (Niekerk et al., 1995) that indicates which variables influence to the stresses generated in structure of plate and structure of PZT. The author mentions that for two-dimensional actuators not clamped and polarized in the z direction, the induced voltage can be written as a function of applied voltage.

$$\Lambda_{pe} = (d_{31}/h_{pe}) \cdot V_a \tag{1}$$

Where:
V_a – Tension applied (V)
d_{31} - Constant piezoelectric of tension.
h_{pe} - Thickness of the piezoelectric material in the z direction (m).
Λ_{pe} - Tension induced

The radius curvature of symmetrical bending in pure circular plate of transverse displacement w(r) is given by:

$$\frac{1}{R_r} = \frac{\partial^2 w}{\partial r^2} \quad , \quad \frac{1}{R_\theta} = -\frac{1}{r}\frac{\partial w}{\partial r} \tag{2}$$

Where:
R_r is the curvature in r-Z plane (m)
R_θ is the curvature in the plane perpendicular (m).

The distribution of tension which is linear through the thickness of the plate is given by:

$$\varepsilon_r^p = \frac{z}{R_r} \quad , \quad \varepsilon_\theta^p = \frac{z}{R_\theta} \tag{3}$$

In the interface between piezoelectric element and plate is placed the tension as a function of ε_r^p and ε_θ^p with z = h_p, may be given by:

$$\overline{\sigma}_r^p = -\frac{E_p h_p}{1-\nu_p^2}\left(\frac{\partial^2 w}{\partial r^2} + \frac{\nu_p}{r}\frac{\partial w}{\partial r}\right) \tag{4}$$

Where:
E_p - is the Young's modulus of plate (N/m^2).
ν_p - Poisson ratio of plate.
H_p - Thickness of plate (m).

For piezoelectric elements the voltage obtained resulting of stresses superposition to the bending in plate and the induced voltage applied the electric voltage.

$$\overline{\sigma}_r^{pe} = \frac{E_{pe} h_p}{1-\nu_{pe}^2} \left(\frac{\partial^2 w}{\partial r^2} + \frac{\nu_p}{r} \frac{\partial w}{\partial r} - \frac{\Lambda_{pe}}{h_p} \right) \quad (5)$$

Where:
E_{pe} - is the Young's modulus of the piezoelectric material (N/m^2).
ν_{pe} - is the Poisson's ratio of the piezoelectric material (dimensionless).

3.2 Control with the use of PVDF and PZT plates

The researches grouped here emphasize the application and use of piezoelectric plates in active vibration control with consequences reduces in audible noise.

The work presented by (Silva, 1998) conducted a theoretical and experimental study using the technique of active control vibration in flexible structures with piezoelectric actuators. The frame under analysis consisted of two rectangular plates of aluminum crimped and separated by the distance of 1.5 mm. The technique intended to attenuate vibration and therefore noise generated in second plates with disturbance occurring in the first plate. This study incorporates a piezoelectric sensor which to generate the reference signal in feedforward controller feeding a piezo actuator bonded on the second structure. A feedback control is employed in order to improve to the system performance. In the realization of controllers are used analog electronic circuits in adjust to gain and phase. The technique control simulated the transfer functions of mechanical system resulting in numerical identification of system parameters on experimental data.

The results of attenuation at around 34 and 18 dB in state steady respectively to the first and second modes of vibration. By transient analyzes with attenuation at level to 22-12 dB. The first mode is near to 1610 Hz and 1720 Hz to second mode

And (Zhou et al., 2000) studied reduction of disturbances varying the thickness of plates with layers sensors and actuators. Already (Fuller and Maillard, 1999) make a studies analytical and experimental obtained the use of active noise control in cylindrical structures.

A study conducted (Niekerk et al., 1995) concerns in sound transmission through an aluminum plate inside at duct. The duct generated a field of wave propagation reducing to one-dimensional acoustic system. The author used a loudspeaker as a source of excitation system generated sine waves. The sound wave is propagated air inner to the aluminum plate turning the vibration. He is presents the mathematical formulation to the voltage induced in the material varying in amount directly proportional to the voltage applied. The experimental control was demonstrated when subjected to a sinusoidal disturbance steady-state in frequency of 1 kHz to achieve a substantial reduction of 20 dB. Above 1200 Hz was not noticed attenuation of sound pressure level, one reason was due to a decrease observed in the gain of controller. Below 200 Hz the attenuation was not observed, in this case, due to the high gain recorded on the controller and the influence of external signals present in the experiment.

With (Cheng and Tang, 1998) at shown the experimental measurements of effective use to active noise control in ducts using a commercial digital device in capture and generation of anti-noise used later in controller. Were employed high speakers as source of control. It is shown through charts that attenuation is affected by the position of the error microphone and is significant when using a microphone positioned on the center line of the duct. In the frequency range that includes the first two vibration modes of the system until 387 Hz. This author manager a attenuation around 30 dB. In according to the author there is a contamination of feedback signal due to cross modes and attenuation observed is greatly reduced.

A study on the use of piezoelectric actuators designed by (Strassberger and Waller, 2000) provided the experimental to the noise reduction occurred in aluminum plate in this study various sensors are fixed to obtain effective control of noise. The development of active noise control requires a numerical model of structure vibration being the use of finite element models to aid the experiments. The results were obtained in frequency range 0-650 Hz generating vibration reduction in order to 15 dB.

3.3 PVDF piezoelectricity

In according (Jivago, 2008) the piezoelectric material generates a potential difference "V", subjected to a mechanical force. The appearance of potential difference caused by application of mechanical force in piezoelectricity and the dielectric material called the piezoelectric effect. The discovery of this effect on poly vinylidene fluoride - PVDF was made by (Kawai, 1969). The electric polarization is directly proportional to the voltage applied.

The greatness measures this electrical property is called the coefficient piezoelectric "*d*", and is defined by:

$$d_{i,j} = \left(\frac{\partial P_i}{\partial \sigma_j} \right)_{E, T_{i,j=1,2,3}} \quad (6)$$

In the which "*P*" represents the polarization, and "*E*" the electric field induced by mechanical tension, "σ" and "*T*" is temperature of material.

The subscripts *i* and *j* in Eq. (6) refers to direction of the mechanical strain in according (Jivago, 2008) and "d" coefficient tensor and consequently also have the same direction. For the case of the PVDF matrix coefficients of "d" the result is nonzero.

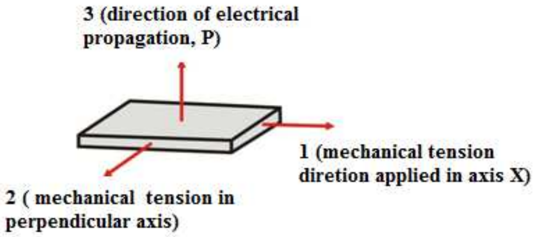

Figure 2. Convention adopted for the subscripts *i* and *j* present in the index of the coefficient piezoelectric material

Table 1 presents some of main physical properties of various materials compared with PVDF (density (ρ), relative permittivity (ε_r'), piezoelectric coefficient (d_{31}), pyroelectric coefficient (p) and coefficient of electromechanical coupling (k)).

Table 1. The main physical properties of some ferroelectric materials

Material	ρ (g.cm^{-3})	ε'_r (1kHz)	d_{31} (pC.N^{-1})	p (mC.m^{-2}K^{-1})	k (%)
PVDF	1,76	8-13	20	40	6
P(VDF-TrFE)	1,9	15 – 20	15 – 30	30 - 40	20
Nylon 11	1,1	4	3	3	_ _ _
PZT-5	7,75	700	171	60-500	34
$BaTiO_3$	5,7	1700	78	200	21
Quartzo	2,86	4,5	2	_ _ _	9

4. CONFIGURATION OF THE DUCTS

The ducts were built in galvanized steel plates with the thickness of 1 mm. The metallic structures of the ducts with glued piezoelectric material were used as a source control of the sound field, tuned to a predetermined frequency. The settings and dimensions of the ducts are similar to the prototypes used in the numerical simulation, as shown in Fig. 3.

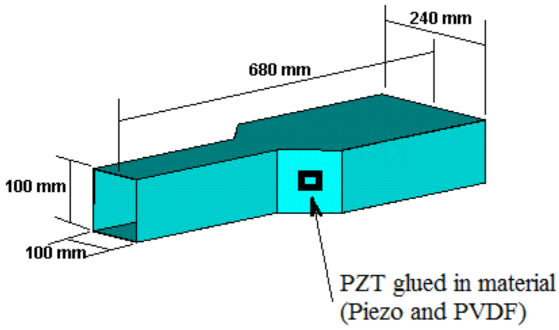

Figure 3: Perspective view of the duct with its variable section.

In all experiments were used a loudspeaker as a source of primary excitation. It was used one generator of pure tone that emitted a harmonic signal in a predetermined frequency of 300 Hz, a resonance frequency of this prototype. It was needed an amplification to the signal injected into the piezoelectric material, glued in the metal plate.

The captured signal was amplified, delayed and adjusted to the electronic circuit. Then, it was given a gain in the amplifier to be used in the control actuator. The measurement of the noise level in the duct was realized with a microphone while a secondary source was turned on or turned off. The primary source was always turned on during the measurement, generating a noise level around 100 dB.

It was used the decibel meter to monitoring the noise level as well as a data acquisition board coupled to a computer with Fast Fourier Transform (FFT), to obtain the corresponding signal in the frequency domain of the captured sound waves.

5. ACOUSTIC FIELD INSIDE THE DUCT

The Active Noise Control is done by producing a cancelling anti-noise signal which has the same amplitude but an opposite phase with the undesired signal (noise). Active Noise Control can be based on feedforward control or feedback control. In the feedforward control the reference noise input is captured before it propagates to the secondary source. In the feedback control the control system tries to cancel the noise without the benefits of a reference input. The hybrid control combines the techniques feedback and feedforward together in same electronic circuit.

For measuring the sound pressure in the variable section duct it was used the equipment arranged in the connection to the block configuration as seen in Fig. 4. The signal of the function generator feeds the speaker in the end.

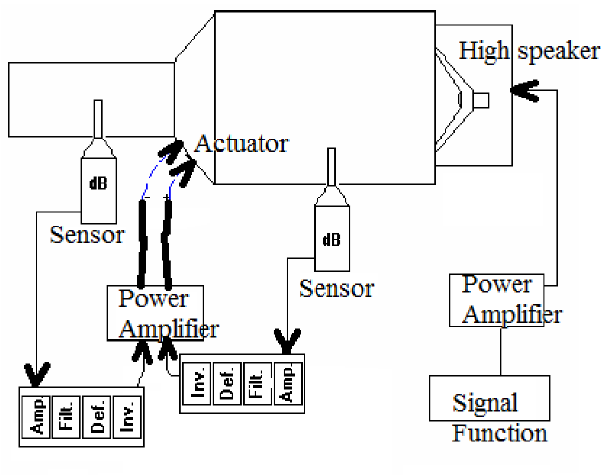

Figure 4: Assembly showing the placement of speaker, microphones and material piezoelectric in duct.

6. HYBRID CONTROL

The hybrid control was used in reducing of noise whose circuits were developed by Silva et al. (1998). The reception of reference sound was performed by the feedforward and feedback process and the sum of the signals corresponds to the hybrid control, as shown in Fig. 5.

The signals received were adjusted in independent circuits. The first adjustment was made by using one reference signal in the feed forward method, monitoring the amplitude and angle phase in order to obtain a greater attenuation of sound. Once kept the adjustment to the feedforward control, it was set the adjustment of the feedback controller, varying the amplitude and angle phase, to achieve the most appropriate attenuation. The result of signal sum is injected in the actuator control, measuring the sound pressure level at the point 1 and 2, as shown in Fig. 6.

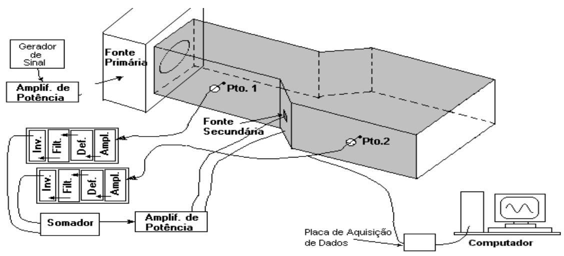

Figure 5: Schematic drawing of transverse section duct, using a hybrid controller.

7. RESULTS TO THE USE OF PZT APPLIED IN VARIABLE DUCT

The ducts and models studied yours characteristics structural and dimensional has been detailed in (Melo, 2004) in other study specific to the tube, sensor and actuator and that would be presented in the many congress. The complete discretization and explaining to the system is large detailed to the sensors, the actuators and prototypes.

The Active Noise Control is done by producing a cancelling anti-noise signal which has the same amplitude but an opposite phase with the undesired signal (noise). Active Noise Control can be based on feedforward control or feedback control. In the feedforward control the reference noise input is captured before it propagates to the secondary source. In the feedback control the control system tries to cancel the noise without the benefits of a reference input. The hybrid control combines the two techniques described. There have values to the behavior of the acoustic vibration levels using PZT plates. The values were obtained and measured by the using the decibel weighted scale "A" in the points 1 and 2 of duct as shown in Fig. 6. The measurements of variations in the sound are shown with and without the use of the control system.

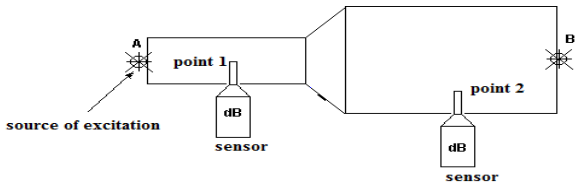

Figure 6. Points of measurements and excitations in the duct.

For this research already has a number expressive of results experimental and numerical simulation using the material PZT in element control which remains to regarding the use of PVDF in the same structure studied and your result is beginning satisfactory. Results were obtained regarding acoustic attenuation in the duct using two different configurations of excitation of the prototype, as shown in Fig. 3. The measurements were performed individually at each end of the duct and the values are shown in Tab. 2. The results were obtained with the use of three different types of controllers as the technique employed, which it was using feed forward, feedback method and hybrid method.

Table 2. - Values obtained by experimental measurement in a duct, exciting him at the end “A”.

Situation / Controller	I		II		I-II	
	Controller (Off) (dBA)		Controller (On) (dBA)		Attenuation Obtained	
	Pto.1	Pto.2	Pto.1	Pto.2	Pto. 1	Pto.2
Feed forward	103,0	99,0	95,0	93,5	8,0	5,5
Feedback	103,0	99,0	86,0	91,0	17,0	8,0
Hybrid	103,0	99,0	77,0	88,0	26,0	11,0

8. CONCLUSION

This paper make a study comparative between different techniques of control and that would be to presented in same congress around the use of smart materials in control of vibration and noise sound. And it’s provide significant contribution in reducing of sound vibration by structure in get a study of bibliography available with the use of advanced materials and innovative techniques.

The controllers using the active type since the passive control techniques in frequency range studied presents a practical constraint. The demand for physical space for duct structures is fundamental where the restriction of airflow is other point that should be analyzed detailed in some cases can to produced and enables a project of the reduced efficiency.

It may be noted that it isn’t just to the use of active control that will provide a gain in physical space of ducts but in their use coupled with piezoelectric actuators produced. The magnitude obtained in around of 10 dB is very significant and useful.

In this moment to the research there is not insufficient result from to the use of PDVF in the structure studied. But the use of these new materials often called "smart" appears so promising for use in control theory due to your versatility and range of work and application. It is expected a intensify development to the technique used and the mathematical characterization of their behavior.

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