VIBROACOUSTIC CONTROL OF DOUBLE-PANEL STRUCTURES USING VISCOELASTIC AND PIEZOELECTRIC MATERIALS - A FINITE ELEMENT REDUCED ORDER MODELING

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ABSTRACT

This work concerns the control of sound transmission through double laminated panels using passive piezoelectric shunt technique. More specifically, the system consists of two sandwich panels (each one composed of two elastic faces and a viscoelastic core) with an air gap in between. Furthermore, piezoelectric patches (connected to a resonant shunt circuit) are surface-mounted on the external faces of the structure in order to damp some specific resonance frequencies of the coupled system. Firstly, a finite element formulation of the fully coupled visco-electro-mechanical-acoustic system is presented. This formulation takes into account the frequency dependence of the viscoelastic material, the electro-mechanical coupling of the piezoelectric elements and the elastoacoustic interaction. A modal reduction approach is then proposed to solve the problem at a lower cost. To this end, the coupled system is solved by projecting the mechanical displacement and the pressure unknown on a truncated basis composed respectively of the first real short-circuit structural modes and the first acoustic modes with rigid boundaries conditions. A static correction is also introduced in order to take into account the effect of higher modes. Moreover, due to the fact that only two electrical variables per piezoelectric patch are used (the electric charge contained in the electrodes and the voltage between the electrodes), they are kept in the reduced system. Finally, numerical examples are analyzed to show the efficiency of the proposed reduced order model.

1 INTRODUCTION

Double-wall structures are widely used in noise control due to their superiority over single-leaf structures in providing better acoustic insulation. Typical examples include double glazed windows, fuselage of airplanes, panels of vehicles, etc.. By introducing a thin viscoelastic interlayer within the panels, a better acoustic insulation is obtained. In fact, sandwich structures with viscoelastic layer are commonly used in many applications for vibration damping and noise control. In such structures, the main energy loss mechanism is due to the transverse shear of the viscoelastic core. However, at low frequency, in particular around the mass-air-mass resonance of the double wall, the acoustic performance of this type of system is greatly deteriorated and the viscoelastic layer is not effective for treating the fall of the sound transmission loss. The aim of this work is to reduce the sound transmission at these resonance frequencies by a passive piezoelectric shunt technique through a full finite element modeling of the problem. In this technology, the elastic structure is equipped with piezoelectric patches that are connected to a passive electrical circuit, called a shunt. The piezoelectric patches transform mechanical energy of the vibrating structure into electrical energy, which is then dissipated by Joule heat in the shunt circuits.

The present work concerns the numerical modeling of noise and vibration reduction of double laminated walls with viscoelastic interlayers by using shunted piezoelectric elements. The objective is to propose efficient reduced order finite element model able to predict the shunt damping around the mass-air-mass resonance of the system.

2 FINITE ELEMENT FORMULATION

Consider the double-wall structure shown in Fig. 1. A prescribed force density $\mathbf{f}$ is applied to the external boundary Γ_t of the structural domain Ω_S. The acoustic enclosure is filled with a compressible and inviscid fluid occupying the domain Ω_F. The cavity walls are rigid except those in contact with the flexible wall structures noted Σ.

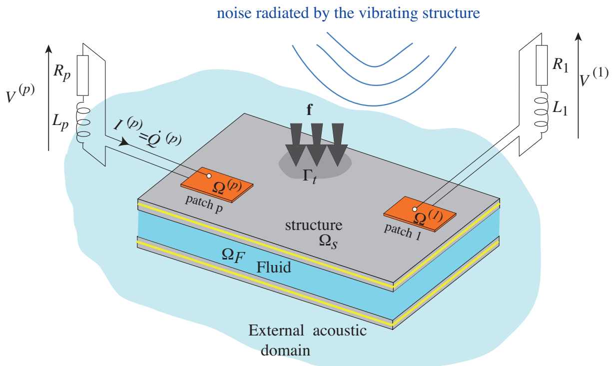

Figure 1. Double sandwich wall structure.

In order to achieve maximum vibration dissipation and acoustic radiation attenuation of selected modes, the passive piezoelectric shunt damping technique is used. Thus, a set of P piezoelectric patches are bounded on the structure surface and connected to resistive or resonant shunt circuits. In this technology, the piezoelectric patches converts a fraction of mechanical energy associated with the structure vibration into electrical energy, which is dissipated by heat through the resistor in the shunt circuits. Each piezoelectric patch has the shape of a plate with its upper and lower surfaces covered with very thin layer electrodes. Moreover, we denotes by $R^{(p)}$ and $L^{(p)}$ the resistance and the inductance of the resonant shunt circuit connected to the pth patch.

The general FE formulation of the electromechanical problem when the piezoelectric patches are RL shunted is [1]

$$
-\omega^2 \begin{bmatrix} \mathbf{M}_u & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{L} & \mathbf{0} \\ \mathbf{C}_{up}^T & \mathbf{0} & \mathbf{M}_p \end{bmatrix} \begin{bmatrix} \mathbf{U} \\ \mathbf{Q} \\ \mathbf{P} \end{bmatrix} + i\omega \begin{bmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{R} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{U} \\ \mathbf{Q} \\ \mathbf{P} \end{bmatrix} + \begin{bmatrix} \mathbf{K}_u + \mathbf{C}_{uV}\mathbf{K}_V^{-1}\mathbf{C}_{uV}^T & \mathbf{C}_{uV}\mathbf{K}_V^{-1} & -\mathbf{C}_{up} \\ \mathbf{K}_V^{-1}\mathbf{C}_{uV}^T & \mathbf{K}_V^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{K}_p \end{bmatrix} \begin{bmatrix} \mathbf{U} \\ \mathbf{Q} \\ \mathbf{P} \end{bmatrix} = \begin{bmatrix} \mathbf{F} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} \quad (1)
$$

where $\mathbf{U}$ is the column vector of nodal values of mechanical displacement; $\mathbf{M}_u$ and $\mathbf{K}_u$ are the mass and stiffness matrices of the structure (elastic structure and piezoelectric patches); $\mathbf{F}$ is the applied mechanical force vector, $\mathbf{P}$ is the column vector of nodal values of acoustic pressure; $\mathbf{M}_p$ and $\mathbf{K}_p$ are the mass and stiffness matrices of the fluid; $\mathbf{C}_{up}$ is the fluid-structure coupled matrix. Moreover, $\mathbf{Q}$ and $\mathbf{V}$ are the column vectors of electric charges and potential differences; $\mathbf{C}_{uV}$ is the electric mechanical coupled stiffness matrix; $\mathbf{K}_V$ is a diagonal matrix filled with the P capacitances of the piezoelectric patches; where $\mathbf{R}$ and $\mathbf{L}$ are the diagonal matrices filled with the electrical resistances and the electrical inductances of the shunt circuits.

3 VISCOELASTIC CORE

In order to provide better acoustic insulation, damped sandwich panels with a thin layer of viscoelastic core are used in this study (Fig. 1). In fact, when subjected to mechanical vibrations, the viscoelastic layer absorbs part of the vibratory energy in the form of heat. Another part of this energy is dissipated in the constrained core due to the shear motion.

In this work, a linear, homogeneous and isotropic viscoelastic core is used. This material is defined by a complex and frequency dependent shear modulus in the form [2]

$$
G^*(\omega) = G^{'}(\omega) + iG^{''}(\omega) \quad (2)
$$

where $G^{'}(\omega)$ is know as shear storage modulus, as it is related to storing energy in the volume and $G^{''}(\omega)$ is the shear loss modulus, which represents the energy dissipation effects.

4 REDUCED ORDER MODEL

The finite element model of Eq. (1) is applicable only to a model which does not imply a prohibitive number of degrees of freedom. To overcome these limitations, we developped a reduced-order formulation for computing the frequency response functions of the fully coupled visco-electro-mechanical-acoustic system. The proposed approach is based on a normal mode expansion and truncation of high-frequency modes. The chosen reduction concerns only the mechanical and acoustical variables $\mathbf{U}$ and $\mathbf{P}$. The electrical unknown field $\mathbf{Q}$ is not concerned by the reduction because the dimension of this vector corresponds to the number of piezo-patches and therefore is very small compared to the mechanical (i.e., displacement in the host structure and the piezo-patches) and acoustical finite element degrees-of-freedom. The mechanical displacement unknown is projected on a truncated basis composed by the first structural *in vacuo* modes with short-circuited patches while the acoustic pressure unknown is projected on a truncated basis composed by the first acoustic normal mode computed from the Helmholtz equation with rigid boundary conditions.

5 EXEMPLE

This example concerns the control of sound transmission through a double laminated glazing panels using shunted piezoelectric patches (Fig. 2-a). The system consists of two identical clamped laminated panels of glass separated by an air cavity. Each laminated glass is composed of two glass plates bonded together by a viscoelastic interlayer. Fig. 2-b presents the normal sound transmission loss of the laminated double wall with and without piezoelectric shunt. The response is calculated with a modal reduction approach using the first 20 in vacuo structural modes and the first 20 acoustic modes of the fluid in rigid cavity with static correction. It can be seen that the resonant magnitude of the second mode (the mass-air-mass resonance) has been significantly reduced. In fact, the strain energy contained in the piezoelectric material is converted into electrical energy and hence dissipated into heat using the RL shunt device.

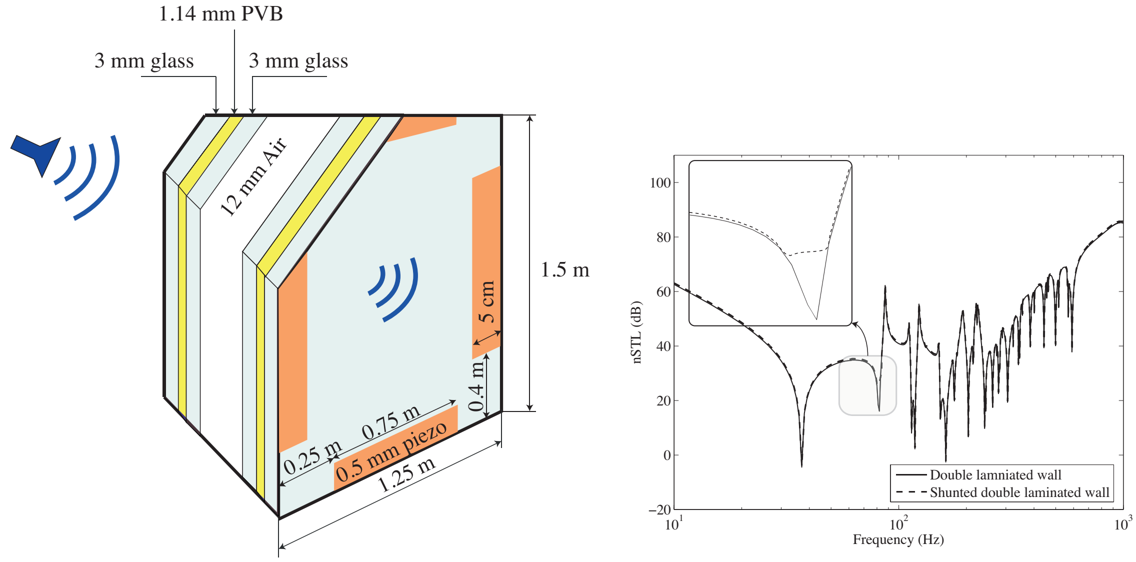

Figure 2: (a) Double laminated glazing panels, (b) Normal sound transmission loss of laminated double panels: control of panel-air-panel resonance by shunted piezoelectric patches.

6 CONCLUSIONS

In this paper, a finite element formulation for sound transmission reduction through double wall sandwich panels with viscoelastic core and piezoelectric shunted patches is presented. A reduced-order model, based on a normal mode expansion, is then developed. The proposed methodology is applied to the control of the mass-air-mass resonance frequency of a double-glazing structure.

REFERENCES

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