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Accurate Designing of Flat-walled Multi-layered Lining System Using Genetic Algorithm for Application in Anechoic Chambers

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Abstract. In anechoic chambers, the flat-walled multilayered acoustic lining systems are cheaper and easier to install than conventional wedge type systems. Sequence, material and thickness of layers are all design variables. By choosing the right configuration, the acoustical performance and overall thickness of flat-walled multilayered systems can be comparable to conventional wedge systems. In this study, the materials considered include air and poroelastic materials such as polyurethane foams, melamine foams, and glass wool. In order to evaluate acoustical performance of a given configuration, the poroelastic materials are modeled using Biot's formulations instead of a simpler impedance method to get more accurate results. A genetic algorithm implemented within ModeFRONTIER optimization software was used to select configurations which have a cut-off frequency of 100 Hz or less. The configuration that met this requirement with the smallest overall thickness was determined optimal. This configuration has an overall thickness of 65.8 cm and is composed of 4 different polyurethane foams. Since a considerable difference was observed between the cut-off frequencies obtained using Biot's model and the simpler impedance method, this justifies the use of Biot's model in the optimization.

Introduction

Anechoic chambers are the rooms with acoustical absorbing walls. They are key requirement in carrying out acoustical experiments in areas such as acoustics engineering. One of the important characteristics of these chambers is cut-off frequency, the frequency that 99 percent of acoustic energy of incident waves with higher frequency will be absorbed. Bernak and Sleeper [1] illustrated the basis of design and construction of anechoic chambers. Two types of anechoic system are already proposed. In conventional one individual unit such as pyramids, wedges and blocks are employed. Cost and complexity of installation are drawbacks of this method. On the other hand, flat-walled multilayered lining is less complicated and cheaper alternative to conventional method. The application of flat-walled multilayered system in anechoic chamber was first proposed by Davern [2]. He examined acoustical performance of different configurations using impedance tube. The obtained results demonstrated that the efficiency of flat-walled lining with appropriate thickness in is comparable with conventional wedge type. In order to speed up design process of lining system, Xu et al. [3] implemented evolutionary algorithm to obtain optimum design set. In their work, to evaluate the acoustical performance, impedance method was implemented and final design set was chosen based on minimizing overall thickness criteria. In the next investigation, Xu et al. [4] used the same optimization method to design and construct an anechoic chamber for experimental tests. Up to now, acoustical performance of flat-walled multilayered systems has been evaluated using equivalent fluid model. This model is not very accurate in low frequencies [5]; hence, more elaborate model is required.

The Transfer matrix method is one of the best candidates for evaluating the acoustic performance of multilayered systems [6, 7]. Biot's equations [8] are used to model and predict the behavior of poroelastic medium and also to derive poroelastic transfer matrix elements. These equations are more accurate than the corresponding equations of the equivalent fluid model [7, 8]. Like impedance method [9, 10], Biot's equations can be generalized to model multilayered system. Overall system transfer matrix is calculated by multiplying transfer matrix of layers.

In order to describe the acoustic field inside medium, Biot's original equations [8] use six displacement fields; three for solid phase and three for fluid phase. However, other representations of Biot's equations have also been introduced to simplify the representation and solution of the problem. Dazel et al. [11] proposed a new representation of Biot's equations called total displacement representation. This representation will be used in the present study to facilitate applying continuity relations in interface of layers.

Since the optimization of lining system is of discrete type, a non-gradient method like genetic algorithm is preferred. Xu et al. [3] used evolutionary algorithm to obtain optimum configurations which give cut-off frequency of 100 Hz. Tanneau et al. [12] employed genetic algorithm to optimize transmission loss in multilayered panels. The solution of this kind of problem is not unique and to choose final design set, decision making strategy is often applied [13].

In the present paper, to obtain more accurate solutions for flat-walled multilayered anechoic lining system, Biot's equations and transfer matrix method are employed. In the first part of the paper, constitutional equations of acoustic and poroelastic medium are described and consequently the transfer matrix of each medium is derived. Eventually, the transfer matrix of the system is obtained using transfer matrix of the layers and employing continuity relations. In the second part of the paper, objective function and constraints are introduced and optimum solutions are obtained using the genetic algorithm. To select final configuration among optimum solutions, decision making strategy is employed. The goal is to minimize the overall thickness of lining with the aim of determining the final configuration to be exploited. In order to demonstrate the worth of using Biot's equations (instead of equivalent fluid model) to predict the behavior of poroelastic medium, cut-off frequency of optimum solutions are obtained using impedance method. Due to the considerable difference between the cut-off frequencies predicted by Biot's model and impedance method, the application of more elaborated model like Biot's model is justified.

Transfer Matrix Method

It is assumed that multilayered anechoic lining is composed of N layers as shown in Fig. 1. The last layer is supported with a rigid wall. The first layer is subjected to incident plane wave. Obtaining the absorption coefficient, the amplitude of reflected wave from the first layer should be determined. All layers are assumed to be laterally infinite and are made from the air and porous materials. Bolten et al. [6] has derived transfer matrix method to handle multilayer acoustic structures. In this method a matrix called transfer matrix is derived to relate the acoustical properties of one point to the corresponding properties of another point in that layer. For multilayered structures, the continuity relations are imposed to relate the acoustical properties of layers to each other. Supposing incident wave is planar, displacement potential function, Φ, is only depended on z and x coordinates. This function is presented by the following relation:

$$\Phi(M) = \{\phi^1 \exp(-j\delta z\cos(\theta)) + \phi^2 \exp(+j\delta z\cos(\theta)\} \exp(-j\delta\sin(\theta)), \tag{1}$$

where M is a point on layer and φ^1 and φ^2 are wave amplitudes of incident and reflected waves, respectively. δ indicates wave number and θ is incident wave angle.

In the next section, displacement potential function will be used to develop the transfer matrix for air and porous mediums.

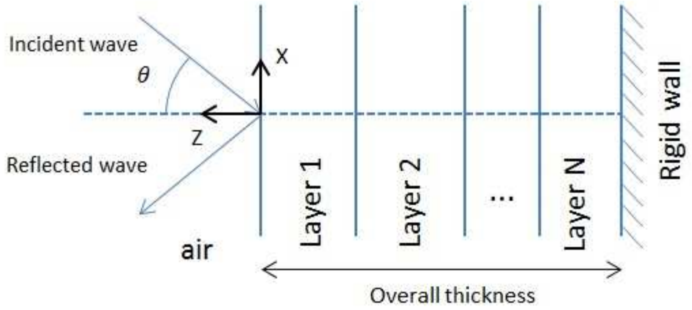

Figure 1. Flat-walled multilayered lining.

Acoustic Medium. The concept of displacement potential function is employed to obtain pressure and displacement of acoustic medium and air. The viscous effect of air is not considered. Determining the amplitude of incident and reflected waves, two physical data are at least necessary. In Cartesian coordinate, pressure and displacement in direction normal to surface (z) are as follows:

$$u_z = \frac{\partial \Phi}{\partial z},$$
$$p = -K\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_z}{\partial z}\right) = -K\left(\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial z^2}\right), \tag{2}$$

where u_x and u_z are displacement components, p is the pressure and K is the bulk modulus of the fluid.

Substituting (1) in the system of Eqs. (2), the displacement and pressure could be found from the following matrix.

$$\begin{Bmatrix} u_z \\ p \end{Bmatrix} = [{}^F H(x,z)] \cdot \{\phi\},$$
$$[{}^F H(x,z)] = \begin{pmatrix} -j\delta\cos\theta\exp(-j\delta z\cos\theta) & j\delta\cos\theta & \exp(j\delta z\cos\theta) \\ \delta^2\rho c_0^2\exp(-j\delta z\cos\theta) & & \delta^2\rho c_0^2\exp(j\delta z\cos\theta) \end{pmatrix}. \tag{3}$$

In the above equations, ρ is the density of air, $c_0 = \sqrt{K/\rho}$ indicates wave propagation speed and j is unit imaginary number. $^{\mathbf{F}}\mathbf{H}$ is the transfer matrix of acoustic medium, where the superscript F denotes fluid as acoustic medium. Wave amplitudes vector is composed of amplitudes of two waves and is represented as follows:

$$\{\phi\} = \begin{pmatrix} \varphi^1 \\ \varphi^2 \end{pmatrix}. \tag{4}$$

Poroelastic Medium. Absorption of acoustic energy is usually done by porous medium such as foams and glass wool. This kind of material is composed of solid and fluid phases. Relative motion of these two phases produces friction by transforming acoustic energy to the heat. Two different descriptions are available to model porous medium: equivalent fluid model [9] and Biot's model [8]. In equivalent fluid model, density and bulk modulus of fluid is defined as a function of frequency. Equivalent fluid is used whenever vibration of solid phase is not considerable. Considering this vibration, Biot's model must be applied.

Biot's original formulation is based on solid and fluid phase displacement fields. Dazel et al. [11] has proposed another alternative displacement formulation without any additional assumption. This new formulation facilitates imposing continuity relations in the interface of layers. In the rest of this paper, Dazel formulation will be applied to derive transfer matrix of porous medium.

Displacement field proposed by Dazel et al. [11] consists of $\mathbf{u}^{\mathrm{w}}$ and solid phase displacement ($\mathbf{u}^{\mathrm{S}}$). $\mathbf{u}^{\mathrm{w}}$ is the function of solid and fluid phase displacements and is defined as

$$\mathbf{u}^{\mathrm{w}} = \phi_p(\mathbf{u}^{\mathrm{F}} + \frac{Q}{R}\mathbf{u}^{\mathrm{S}}), \tag{5}$$

where ϕ_p is porosity, Q and R are Biot's model parameters [8]. $\mathbf{u}^{\mathrm{w}}$ is the average of microscopic fluid displacement on total the volume of porous medium [11]. Stress-stain relation and pressure are defined as follows:

$$\hat{\sigma}_{ij}^{S} = 2N\varepsilon_{ij}^{S} + \hat{A}e\delta_{ij}, \qquad p_f = K_{eq}\zeta. \tag{6}$$

Stress $\hat{\sigma}_{ij}^{S}$ proposed by Atalla et al. [14] is called jacked stress tensor or in vacuo stress tensor of solid phase. Pressure of fluid is denoted by p_f and compressibility of equivalent fluid by K_{eq}. ζ and K_{eq} is defined as follows

$$\begin{aligned} &\zeta = \nabla\cdot\mathbf{u}^{\mathrm{w}}, \\ &K_{eq} = \frac{k_f}{\phi_p + (1-\phi_p)\dfrac{\tilde{K}_f}{\tilde{K}_s} - \dfrac{\tilde{K}_b\tilde{K}_f}{\tilde{K}_s^{\,2}}}, \end{aligned} \tag{7}$$

where $\tilde{K}_b$ is the bulk modulus of elastic frame at constant fluid pressure. $\tilde{K}_s$ is the bulk modulus of elastic frame and $\tilde{K}_f$ is the bulk modulus of fluid phase. N indicates shear modulus of solid phase, δ_{ij} is kronecker delta, $\hat{A} = A - (Q^2/R)$, $e = u_{i,i}^{S}$ is solid phase dilatation and ε_{ij}^{S} is solid phase strain, defined as follows

$$\varepsilon_{ij}^{S} = \frac{1}{2}(u_{i,j} + u_{j,i}). \qquad i, j = 1,2,3 \tag{8}$$

Considering new alternative generalized coordinates, equation of motion can be given as follows [11]

$$\begin{aligned} &\nabla\cdot\hat{\boldsymbol{\sigma}}(\mathbf{u}^{\mathrm{S}}) = -\omega^2\tilde{\rho}_s\mathbf{u}^{\mathrm{S}} - \omega^2\tilde{\rho}_{eq}\tilde{\gamma}\mathbf{u}^{\mathrm{w}}, \\ &K_{eq}\nabla\boldsymbol{\zeta} = -\omega^2\tilde{\rho}_{eq}\tilde{\gamma}\mathbf{u}^{\mathrm{S}} - \omega^2\tilde{\rho}_{eq}\mathbf{u}^{\mathrm{w}}, \end{aligned} \tag{9}$$

where

$$\begin{aligned} &\rho_1 = (1-\phi_p)\rho_m, && \rho_2 = \phi_p\rho_f, \\ &\rho_{12} = -\phi_p\rho_f(\alpha_\infty - 1), && \tilde{\rho}_{12} = \rho_{12} - \phi_p^{\,2}\frac{\sigma G(\omega)}{j\omega}, \\ &\tilde{\rho}_{22} = \rho_2 - \tilde{\rho}_{12}, && \tilde{\rho}_{11} = \rho_1 - \tilde{\rho}_{12}, \\ &\rho_{eq} = \frac{\tilde{\rho}_{22}}{\phi_p^{\,2}}, && \tilde{\alpha} = \frac{\tilde{\rho}_{22}}{\rho_2}, \\ &\tilde{\gamma} = \frac{\phi_p}{\tilde{\alpha}} - \gamma', && \gamma' = 1 - \frac{\tilde{K}_b}{\tilde{K}_s}. \end{aligned} \tag{10}$$

In above expressions, ρ_m and ρ_f are solid and fluid phase mass densities, respectively. ρ_{12} is inertial coupling coefficient related to geometric factor. α_∞ represents tortuosity, σ is fluid flow resistivity and $G(\omega)$ indicates frequency dependent function that takes the viscosity of saturated air in immobile skeleton into account. The following relation is called Johnson model [15],

$$G(\omega) = [1 + (\frac{2\alpha_\infty q_0}{\phi_p \Lambda})^2 \frac{j\omega}{\nu}]^{1/2}, \tag{11}$$

where Λ is viscous characteristic length and q_0 is static viscous permeability and $\nu = \eta / \rho_f$ which η is the structural damping.

In order to solve equations of motion, displacement potential function description is utilized. Solid and fluid phase displacements are defined based on scalar function φ and vectorial function $\mathbf{\Psi}$ giving by

$$\begin{aligned} \mathbf{u}^S &= \nabla\varphi^S + \nabla\times\mathbf{\Psi}^S, \\ \mathbf{u}^F &= \nabla\varphi^F + \nabla\times\mathbf{\Psi}^F. \end{aligned} \tag{12}$$

Inserting Eq. (12) in (9), three kinds of propagating waves can be obtained; two compression waves and one shear wave. Solid and fluid phase displacement are expressed according to

$$\begin{aligned} \mathbf{u}^S &= \nabla\varphi_1 + \nabla\varphi_2 + \nabla\times\mathbf{\Psi}, \\ \mathbf{u}^F &= \mu_1\nabla\varphi_1 + \mu_2\nabla\varphi_2 + \nabla\times\mathbf{\Psi}, \end{aligned} \tag{13}$$

where

$$\begin{aligned} &\mu_i = \tilde{\gamma}\frac{\delta_{eq}^2}{\delta_i^2 - \delta_{eq}^2}, \qquad\qquad i,j = 1,2 \\ &\delta_1^2, \delta_2^2 = \frac{(\delta_{s2}^2 + \delta_{eq}^2) \pm \sqrt{(\delta_{s2}^2 + \delta_{eq}^2)^2 - 4\delta_{eq}^2\delta_{s1}^2}}{2} \\ &\delta_3 = \omega\sqrt{\rho / N}, \qquad \mu_3 = -\tilde{\gamma}, \end{aligned} \tag{14}$$

with

$$\begin{aligned} &\delta_{eq} = \omega\sqrt{\tilde{\rho}_{eq} / K_{eq}}, \qquad \delta_{s1} = \omega\sqrt{\rho / \hat{P}}, \\ &\delta_{s2} = \omega\sqrt{\rho_s / \hat{P}}, \qquad \hat{P} = \hat{A} + 2N, \\ &\rho = \rho_s - \tilde{\gamma}^2\rho_{eq}, \qquad \rho_s = \rho_1 + \rho_2(Q/R)^2 - \tilde{\rho}_{12}\frac{\gamma'^2}{\phi_p^{\ 2}}. \end{aligned} \tag{15}$$

Wave numbers of these three kinds of wave are denoted by δ_i. The ratio of fluid phase displacement to solid phase displacement is denoted by μ_i.

Assuming porous skeleton material is very stiff, following simplifications are achieved. Usual sound absorbing materials satisfy this assumption [11].

$$\left|\frac{\tilde{K}_b}{\tilde{K}_s}\right| \ll 1, \qquad \left|\frac{\tilde{K}_f}{\tilde{K}_s}\right| \ll 1,$$

$$\gamma' = 1, \qquad \tilde{R} = \phi_p \tilde{K}_f, \quad \tilde{K}_{eq} = \frac{\tilde{K}_f}{\phi_p}. \tag{16}$$

Regarding these assumptions, the following result is derived

$$\mathbf{u^w} = \mathbf{u^t}, \tag{17}$$

where $\mathbf{u^t}$ is called total displacement of porous materials and is defined as

$$\mathbf{u^t} = \phi \mathbf{u^f} + (1-\phi)\mathbf{u^s}. \tag{18}$$

In Eq. (16), $\tilde{K}_f$ is the frequency dependent function which takes thermal effects into account. The following relation could be employed for $\tilde{K}_f$ [7]

$$\tilde{K}_f = \gamma P_0 \Bigg/ \left[\gamma - \frac{\gamma - 1}{1 + \dfrac{\nu'\phi}{j\omega q_0^{'}} G'(\omega)} \right]. \tag{19}$$

There are different model for $G(\omega)$. Using simplified Lafarge model [7], we have

$$G^{'}(\omega) = \left[1 + \left(\frac{2q^{'}}{\phi_p \Lambda^{'}}\right) \frac{j\omega}{\nu^{'}} \right]^{(1/2)}, \tag{20}$$

where Λ' is the thermal characteristic length and $\nu' = \nu / B^2$ where B^2 is Prandtl number. q' is static thermal permeability. P_0 is ambient mean pressure and γ is ratio of constant pressure to the constant volume specific heat coefficient.

In Eqs. (13), displacement potential function, φ_i & $\mathbf{\Psi}$ are obtained by inserting Eqs. (13) in (9) as follows

$$\begin{aligned} \varphi_i &= e^{j\delta_i x \sin\theta_i} \left[\varphi_i^1 e^{-j\delta_i z \cos\theta_i} + \varphi_i^2 e^{j\delta_i z \cos\theta_i} \right], \qquad i = 1,2 \\ \Psi &= e^{j\delta_3 x \sin\theta_3} \left[\psi^1 e^{-j\delta_3 z \cos\theta_3} + \psi^2 e^{j\delta_3 z \cos\theta_3} \right]. \end{aligned} \tag{21}$$

Inserting above two Eqs. in (6) and (13), eventually transfer matrix relating physical parameters to amplitudes of waves will be developed,

$$\begin{Bmatrix} p^F \\ t_z^S \\ t_x^S \\ u_z^F \\ u_z^S \\ u_x^S \end{Bmatrix} = \left[{}^{\mathbf{P}}\mathbf{H(x,z)} \right] \begin{Bmatrix} \phi_1^1 \\ \phi_1^2 \\ \phi_2^1 \\ \phi_2^2 \\ \psi^1 \\ \psi^2 \end{Bmatrix}, \tag{22}$$

where t_z^S and t_x^S are solid phase stress components, p^F is fluid phase pressure and $\mathbf{u}^\mathbf{S}$ and $\mathbf{u}^\mathbf{F}$ are fluid and solid phase displacement components, respectively. ${}^\mathbf{P}\mathbf{H}$ is transfer matrix of porous medium.

Continuity Relations. In the flat-walled multi-layered lining system, two different combinations of interferences are possible. These two combinations are taken into account as follows:

- Fluid / poroelastic interface:

Continuity relations between fluid and porous layers involve normal displacement, pressure and stress components.

$$\begin{aligned} &\mathbf{u}^a \cdot \mathbf{n} = \mathbf{u}^t \cdot \mathbf{n}, \\ &p_a = p_f, \qquad \hat{\boldsymbol{\sigma}}^S \cdot \mathbf{n} = 0, \end{aligned} \tag{23}$$

where $\mathbf{u}^a$ and $\mathbf{u}^t$ are air and poroelastic displacement vector, respectively. $\mathbf{n}$ is normal vector to interference surface. p_a and p_f are pressure of air in acoustic medium and fluid phase of poroelastic medium, respectively.

- Poroelastic/Poroelastic interface:

Continuity relations between two different poroelastic layers involve solid displacement vector, $\mathbf{u}^\mathbf{S}$, total displacement vector, $\mathbf{u}^\mathbf{t}$ and fluid pressures and stress components as follows

$$\begin{aligned} &\mathbf{u}_1^S = \mathbf{u}_2^S, \qquad \mathbf{u}_1^t \cdot \mathbf{n} = \mathbf{u}_2^t \cdot \mathbf{n}, \\ &p_{f,1} = p_{f,2}, \qquad \hat{\boldsymbol{\sigma}}_1^S = \hat{\boldsymbol{\sigma}}_2^S. \end{aligned} \tag{24}$$

Pressure Reflection and Absorption Coefficient Spectrum. Obtaining the transfer matrix of each layer, the total transfer matrix of whole system can be found using transfer matrix of layers and continuity relations. Total transfer matrix of system relates the pressure and normal velocity of one face to another face, which lets to find the reflected wave amplitude. Supposing the amplitude of reflected wave is determined, pressure reflection factor (r) and absorption coefficient (α) are obtainable using following Eqs. [7]

$$r = (Z\cos\theta - Z_0)/(Z\cos\theta + Z_0), \tag{25}$$

$$\alpha = 1 - |r|^2, \tag{26}$$

where the $Z_0 = \sqrt{\rho c_0}$ is the air characteristic impedance and $Z = P/\dot{u}_z^t$ is surface impedance of the layer which exposed to incident wave. θ is the oblique wave incident angle as shown in Fig. 1.

Optimization

Definition of Problem. Optimization of acoustical performance of flat-walled multilayered lining system is a significant subject to achieve satisfying performance comparing with traditional individual unit type. Acoustical performance of the lining system is influenced by number and sequence of layers and thickness of material for each layer. The aim of optimization is to find those configurations that satisfy the cut-off frequency of 100 Hz. The solution of optimization is not unique. In order to select a solution, the designer needs to define criteria to guide him in selection procedure. These criteria are called goals.

Investigated materials in optimization are air and materials given in Table 1. The material ID 1 belongs to air which its density and speed of sound are 1.12 kg/m^3 and 340 m/s, respectively. These materials include polyurethane foams, melamine foams and glass wools. In this Table, E and ν_p are young modulus and Poisson's ratio of skeleton, respectively. These materials are chosen because their parameters are available and flow resistivity of these materials is suitable to obtain the specified cut-off frequency [16, 17].

The constraints of optimization problem have been set as:

- Predefined materials (listed in Table 1).
- Maximum number of layers for lining system is 4.
- Maximum thickness of each layer is 30 cm.

Optimization is performed in the frequency range from 100 to 1000 Hz. This frequency range is chosen due to the cut-off frequency and the fact that sound absorption is usually more effective for higher values of frequency. Reflection coefficient spectrum for lining system is calculated using tranfer matrix method as described in previous section and is used to obtain objective function. Finally genetic algorithm will be employed to obtain optimum solutions. Design variables are sequence of layers and thickness of each layer.

Objective Function. In multiobjective optimization problems, the objective function could be a vector containing more than one function that should be minimized or maximized by optimization algorithm. In order to achieve the desired configuration that satisfies 100 Hz cut-off, Xu et al. [3] defined reflection coefficient of multilayered lining in specified frequencies as objective functions. They defined more than one objective function to cover desired frequency range and subsequently employed multiobjective optimization to find optimum solutions. Unlike Xu et al. [3], in the present work, only one objective function is defined and conceptually same results are obtained. The objective function is defined in such a way to guide optimization algorithm toward the solutions that their reflection coefficient spectrum in specified frequency range, give the cut-off frequency of 100 Hz. Reflection coefficients in specified frequencies are calculated using transfer matrix method as described in the previous section. The objective function is defined as follows

Table 1. Materials investigated [16], [17] and [7].

ID	Property	ϕ_p	σ $(N.s/m^4)$	α_∞	Λ (μm)	Λ' (μm)	ρ_m (kg/m^3)	E	ν_p	η
2	Foam 1	0.97	600	1.06	420	600	856	144000	0.3	0.1
3	Foam 2	0.97	900	1.07	400	520	856	144000	0.3	0.1
4	Foam 3	0.99	1000	1.07	350	600	2570	144000	0.3	0.1
5	Foam 4	0.97	1300	1.07	300	490	856	144000	0.3	0.1
6	Foam 5	0.99	1400	1.05	290	500	2570	144000	0.3	0.1
7	Foam 6	0.99	1700	1.04	290	490	2570	144000	0.3	0.1
8	Foam 7	0.99	1900	1.04	260	420	2570	144000	0.3	0.1
9	Foam 8	0.98	2600	1.07	210	380	1285	144000	0.3	0.1
10	Foam 9	0.97	3800	1.07	200	220	856	144000	0.3	0.1
11	Foam 10	0.98	10000	2.3	60	310	1285	144000	0.3	0.1
12	Foam 11	0.98	19000	1.7	20	270	1285	144000	0.3	0.1
13	Melamine foam	0.96	15300	1.02	105	205	225	400000	0.4	0.1
14	Glass wool 1	0.98	35000	1	60	150	480	10000	0	0.2
15	Glass wool 2	0.98	55000	1	44	130	800	50000	0	0.2

$$G = \sum_i H(r_i - 0.1), \quad i=100,125,150,...,1000, \tag{27}$$

where H is Heaviside operator and r is pressure reflection coefficient in normal incident and subscripts are the frequencies in which r is calculated. Those configurations that make the value of defined objective function to be zero, satisfy the cut-off frequency of 100 Hz.

Genetic Algorithm. Genetic algorithm [18] is an evolutionary algorithm that mimics the process of natural evolution to generate optimal solutions based on principle of survival of the fittest generation. The principle of genetic algorithm is very simple. The design parameters are encoded in a chromosome. Then the initial populations are generated randomly. The individual of this initial population is evaluated using fitness function. Individuals of next generation are obtained from best of previous generation using operations of mutation and crossover. Repeating the procedures for several generations, the best individuals offer a good approximation of optimal solutions. The maximum number of layers, sequence of materials and their thicknesses are considered as genes. During optimization procedure, these chromosomes change through mutation and crossover operators.

Parameters of GA. There are two basic operators for genetic algorithm that aim to provide diversity in next generation.

- Crossover probability is an operator that combines more than one parent to produce the next generation chromosomes. In this study a crossover rate of 0.65 is used.
- Mutation rate is an operator that introduces random genes to chromosome to provide diversity. This operator always takes place after crossover operator. Mutation avoids the algorithm to trap in local minimums by pushing the search toward other random parameter space. Mutation rate of 5% is used in current work.

Other parameters that must be specified before employing the algorithm are:

- Maximum number of generation shows that how many times the algorithm must be repeated. This must be chosen in a way to guaranty the algorithm convergence. For this study, 10 generations provide adequate solutions and further generations provide almost same results.
- Population size is the number of individuals having potential to be the solutions of the problem. In this study the initial population of 100 is used to attain convergence.

In order to perform optimization algorithm, ModeFRONTIER4 as a multiobjective optimization software is selected. ModeFRONTIER is a design environment with the ability of coupling with other engineering software like Matlab. ModeFRONTIER performs the algorithm while the objective function is evaluated in Matlab environment. Design parameters are chosen as mentioned above and other necessary parameters are set to be default.

Results of Optimization

The results of optimization include 16 configurations as summarized in Table 2, where "I. M." and "B. M." are the abbreviations for impedance method and Biot's model, respectively. These configurations are sorted from low to high overall thickness, between 65.8 cm and 81.1 cm, which is comparable with the corresponding overall thickness of traditional wedge type system. For example, Easwaran et al. [19] designed a wedge from glass wool with overall thickness of more than 1 meter for cut-off frequency of 100 Hz.

Melamine foam and glass wool have not been appeared in final results, maybe because of their high flow resistivity. Also, air has not been used in any configuration. This is due to the fact that air doesn't absorb energy. Furthermore, small thickness of air doesn't significantly change the wave phase in low frequency range. In most of configurations in Table 2, flow resistivity of materials increases from the first to last layer which allows incident wave penetrates easily to multilayered lining system and could be absorbed by it.

Considering our goal of minimizing the overall thickness of lining system, the first configuration in Table 2, appeared to be the best option. For this configuration, the pressure reflection spectrum is plotted in Fig. 2 based on Biot's model and Impedance method prediction. The deviation between prediction of these two models are expected in frequencies below 300 Hz, where vibration of solid phase which is not considered by equivalent fluid model, changes the acoustical behavior of poroelastic materials [5].

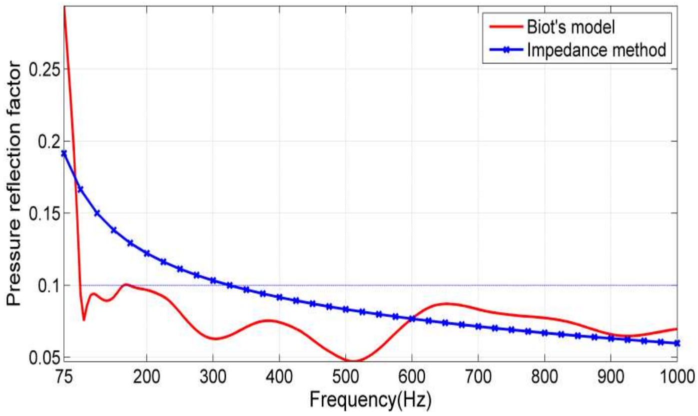

Figure 2. Pressure reflection spectrum for option 1 in Table 2.

Table 2. Optimization results.

	Material ID of each layer				Thickness of each layer (cm)				Overall thickness (cm)	Cut-off frequency (Hz)	
Option ID	Layer 1	Layer 2	Layer 3	Layer 4	Layer 1	Layer 2	Layer 3	Layer 4		I.M.	B.M.
1	2	6	10	11	14.7	25	21	5.1	65.8	320	100
2	2	6	7	10	17.6	11.3	12.5	24.5	65.9	240	100
3	2	6	7	10	17.6	8.3	16.7	24	66.6	240	100
4	2	8	10	…	22.5	21.1	23.9	…	67.5	220	97
5	2	6	7	10	17.6	8.3	18.5	23.4	67.8	240	97
6	2	3	5	10	17.6	9.8	17.3	27.5	72.2	240	95
7	2	4	10	9	14.9	29	21	7.9	72.8	275	96
8	2	4	10	9	14.9	29	21.3	7.9	73.1	240	96
9	2	7	10	…	24.1	27.4	22.1	…	73.6	245	97
10	2	7	10	…	24.6	27.4	22.9	…	74.9	245	98
11	2	5	8	10	25.3	11.7	15.3	22.8	75.1	240	95
12	2	7	10	…	24.4	29	21.8	…	75.2	250	100
13	2	8	13	5	30	28.8	4.8	12.9	76.5	250	98
14	2	6	10	…	26.1	23	29.1	…	78.2	250	100
15	2	6	10	…	28	25.3	27	…	80.3	260	95
16	2	6	10	11	30	25	21	5.1	81.1	250	92

Conclusion

Flat-walled multilayer lining system is an attractive option for designing anechoic chamber. It is cost effective and simple in production and installation. Comparing this system with traditional wedge type system, the results proved that this method can compete easily in the sense of thickness and performance.

Davern [2] used impedance method and trial and error strategy in order to obtain the configurations that give desired cut-off frequency. However, this procedure was time consuming and tedious. In previous investigation, the evolutionary algorithm was successfully applied to find configurations which give desired cut-off frequency [3, 4]. In the present paper, genetic algorithm has been employed as an optimization strategy to lead the configurations to provide desired cut-off frequency. With the purpose of evaluating acoustical performance, Biot's theory and transfer matrix method have been used to model poroelastic medium which gives more accurate results in frequencies below 300Hz [5]. With the aim of optimization, air and 14 other materials including polyurethane foams, melamine foam and glass wool have been used as prime materials. The results offer a combination of different materials with flow resistivity increasing gradually from frontal layers to the last layer. This allows gradually penetration of wave into the lining system and subsequently increasing the absorption efficiency. Among various configurations introduced by optimization algorithm, the thinner option was 65.8 cm in thickness, which easily proofs the applicability of multilayered lining system for application in anechoic chamber.

Finally, in order to justify employing elaborate model, cut-off frequency of all optimum options calculated by equivalent fluid model have been compared with the corresponding cut-off predicted using Biot's model. Significant deference between these two predicted cut-off frequencies proved that in this context, applying more complex model is useful.

References

[1] L.L. Beranek and H.P Sleeper: J. Acoust. Soc. Am. Vol. 18 (1946), p.p. 140-150

[2] W.A Davern, In: *Proceedings of 10th international congress on acoustics* (1980).

[3] J. Xu, J. Nannariello and F.R. Fricke: J. Appl. Acoust. Vol. 65 (2004), p.p. 1009-1026

[4] J. Xu, J.M. Buchholz and F.R. Fricke: J. Acoust. Soc. Am. Vol. 118(5) (2005), p.p. 3104-3109

[5] R. Panneton: J. Acoust. Soc. Am. Vol. 122(6) (2007), p.p. 217-222

[6] J.S. Bolten, N.-m. Shiau and Y.J. Kang: J. Sound Vib. 191 (1996), p.p. 317-347

[7] J.F. Allard: *Propagation of sound in porous media* (Elsevier applied Science, New York 1993).

[8] M.A. Biot: J. Acoust. Soc. Am. Vol. 28 (1956), p.p. 168-191

[9] M.E. Delany and E.N. Bazley: Appl. Acoust., Vol. 3 (1970), p.p. 105-116

[10] I.P. Dunn and W.A. Davern: Appl. Acoust. Vol. 19(5) (1986), p.p. 321-334

[11] O. Dazel, B. Brouard, C. Depollier and S. Griffiths: J. Acoust. Soc. Am. Vol. 121(6) (2007), p.p. 3509-3516

[12] O. Tanneau, J.B. Casimir and P. Lamary: J. Acoust. Soc. Am. Vol. 120(3) (2006), p.p. 1227-1238

[13] C.M. Fonseca and P.J. Fleming: IEEE Trans. Syst. Man. Cybernet Part A Vol. 28(1) (1998), p.p. 26-37

[14] N. Atalla, N. Panneton and P. Debergue: J. Acoust. Soc. Am. Vol. 104(3) (1998), p.p. 1444-1452

[15] D. Johnson, J. Koplik and R. Dashen: J. Fluid Mech. Vol. 176(6) (1987), p.p. 379-402

[16] O. Doutres, N. Atalla and K. Dong: J. Appl. Phys. Vol. 110(6) (2011), art. no. 064901

[17] P. Leroy, N. Atalla and A. Berry: J. Acoust. Soc. Am. Vol. 126(6) (2009), p.p. 2873-2882

[18] D.E. Goldberg: *Genetic Algorithms for search, optimization and Machine learning* (Addison-Wesley, Reading 1989).

[19] V. Easwaran and M.L. Munjal: J. Sound Vib. Vol. 160(2) (1993), p.p. 333-350

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