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Multi objective optimization of sound transmission across laminated composite cylindrical shell lined with porous core investigating Non-dominated Sorting Genetic Algorithm

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The current formulation applies Non-dominated Sorting Genetic Algorithm (NSGA-II) as well as First-order Shear Deformation Theory (FSDT) to optimize Sound Transmission Loss (STL) of the laminated composite cylindrical shell lined with a porous material subjected to a plane sound wave. Therefore, in the first part of the paper, the Extended Full method [29] is employed to provide an exact solution based on three dimensional elasticity theory as well as investigating the well-known Helmholtz decomposition to present fluid pressure, the displacement fields and the solid stresses. Subsequently, some configurations are brought up to illustrate the accuracy of the present results. Furthermore, this paper also clarifies the importance of applying porous layer by demonstrating the direct influence between porous layer thicknesses and STL of the structure particularly in high frequency region. Consequently, in the second part of the paper the NSGA-II method is applied to multi objective optimize of sound transmission into such structure taking account the appropriate Pareto front which result in substantial improvement on the performance of the system based on minimizing the weight as well as maximizing sound transmission. Therefore, this procedure is followed by considering suitable design variables to designate what combination of design variables could result in a composite shell satisfying the sound insulation.

1. Introduction

In recent years, the importance of using high-performance materials in many fields of engineering has been increased. Among of this material, laminated composite due to high stiffness and light weight has been absorbed engineer's attention in various technical applications. According to this fact, along with considering the sensitively to structural vibration and noise, laminated composite shells significantly have been applied in aerospace, marine, mechanical and automotive engineering. It is essential to mention that it is possible that the vibration of the outer shell of the fuselage of the modern aircraft increase and leads to high-level noise by transmitting into the cabin. In fact, the noise which is transmitted into such structure due to low density is a critical issue, particularly at high frequency. For this reason, the reduction of this noise transmission into such structure is considerably attempted by entering the porous material as an intermediate layer. A porous layer composed of a frame (solid phase) surrounded by fluid (liquid phase). The porous materials generally arranged in two brands. The first one which enhances stiffness and moderate sound absorption is made of ceramics and metals. The second one which is flexible and soft is supplied by polymer foam and sponges.

To model porous material, a lot of theories with various approximate calculations have been discussed. Likewise, Biot [1] for the first time proposed a model of elastic wave propagation through a fluid-filled poroelastic medium. Later, the Biot's theory was expanded by Bolton et al. [2] to analyze Sound Transmission Loss (STL) through double panels beside poroelastic material for various configurations. This theory is well-known as the Full method. In this theory, the oblique plane sound waves are managed by taking account two longitudinal waves which one of them propagates in elastic frame and the other propagates in a fluid medium. However, the shear wave is the rotational wave which propagates in an elastic frame. Then, the simplified method was applied by Lee and Kim [3] to calculate STL through structures with poroelastic liners. In this research work poroelastic material was considered as an equivalent fluid by keeping the strongest wave among of three. It is noteworthy that two steps were taken account to obtain this procedure. In the first step, Full method was

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used to solve an equivalent flat double panel problem of infinite extent. Besides, actual geometry was modeled to solve the problem as a second step. Following the last research, symmetric wave propagation in the porous medium was investigated by Hundal and Kumar [4]. Literatures demonstrate that several significant works have been done on the poroelastic cylindrical shells because of their diverse applications. Hasheminejad et al. [5] considered interaction of a plane compressional sound wave with a cluster of two fluid-saturated porous elastic cylinders submerged in a boundless acoustic medium. The frequency equation for radial vibrations of a poroelastic cylinder was determined by Abbas [6]. After, Tajuddin et al. [7] obtained the frequency equation of circumferential waves for a permeable and an impermeable surface of an infinite hollow poroelastic cylinder in the presence of dissipation. Furthermore, the flexural wave propagation in coated poroelastic cylinders of infinite extent was studied by SA. Shah [8] employing Biot's theory. Noise transmission, measured by STL across cylindrical shell, has been proposed by many authors. An analytical model of STL of sound energy was studied by Smith [9] through a thin isotropic elastic cylindrical shell. Following the previous work, White [10] considered sound transmission into finite circular shell, taking account the ring and coincidence frequencies. Smith's work was developed by Koval [11,12] for predicting STL through the aircraft fuselage as an infinite circular cylindrical shell for orthotropic and isotropic shells. Blaise et al. [13] developed the theoretical model of sound transmission through cylindrical shell impinged upon plane sound wave with two incident angles. After many years, Blaise's studies were extended by Tang et al. [14] through circular cylindrical shell sandwiching a layer, by considering that the model was excited by an oblique sound wave with two incident angles. Lee and Kim [15] conducted their research on analytical and experimental models by considering all three displacement fields, for studding STL across the infinitely large circular cylindrical shell. Love's equation was used for the shell vibration motions and inside cavity was assumed to be anechoic. An exact solution in a series form according to the Classical Shell Theory (CST) and First-order Shear Deformation Theory (FSDT) was proposed by Daneshjou et al. [16–18] through laminated composite and orthotropic cylindrical shell. In these research works all three displacement fields were considered to model the shell motion. Hasheminejad et al. [19,20] investigated accomplishment between sound pressure and the FGM structures by Resonance scattering theory on the FGM cylindrical shell under a plane acoustic wave using a two-dimensional theory. Furthermore, in another research work, Vibro-acoustic behavior of a hollow FGM cylinder was taken into account. Daneshjou et al. [21] conducted their attention to predict sound transmission through the FGM cylindrical shell. The considerable achievement of their work was taking account of the effects of the shear and rotation terms; particularly in lower R/h ratio, the accurate results were obtained from Third-order Shear Deformation Theory (TSDT). Besides, Simplified method was applied in [22] to calculate sound transmission through a laminated composite double-walled cylindrical shell lined with porous materials. In following, another research done by Gao et al. [23] across the propagation of seismoelectric waves in a fluid-filled poroelastic hollow cylinder. An analytical model of STL was achieved by Zhou et al. [24] through a double shell lined with poroelastic material containing the influence of external flow. It is necessary to mention that the CST was used for the inner and outer skins whereas an equivalent fluid method based on the Biot's Theory was applied for the intermediate layer. Talebitooti et al. [25,26] suggested a model of STL through the double-wall panels sandwiching a layer of air gap employing Full method. They also extended their last studies, on the acoustic behavior of double walled composite panels that poroelastic material was added between the layers by using Classical Laminated Plate Theory (CLPT). It is noteworthy that structures with an infinite multilayer cylinder are suitable for increasing STL. Therefore, an analytical model was provided by Magniez et al. [27,28] on the multilayer cylinder which involved orthotropic skins employing FSDT while an isotropic polymer core was modeled based on three-dimensional elasticity theory to analyze the motion of the thick core. Meanwhile, another model of a sandwich cylinder with a poroelastic core was considered to determine STL. Although, the theories for analyzing the motion of the two papers were the same, the different materials were used as an intermediate layer. Consequently, another paper was prepared by Talebitooti et al. [29,30] to obtain sound transmission through poroelastic cylindrical shell. Moreover, it is essential to mention that the procedure for obtaining the results followed based on Extended Full method through the double-walled cylindrical shell consists of isotropic skins and poroelastic core. Alongside, three-dimensional elasticity theory was investigated in another paper to calculate sound transmission across thick-walled cylindrical shell. The inspection of this work displayed that when the effect of rotational terms enhance, CST and higher order shell theories doesn't have enough accuracies especially at high frequencies. Just recently, Talebitooti et al. [31,32] investigated 3D elasticity theory of wave propagation across the STL of the thick-wall cylindrical shells in the presence of external and mean air-gap flow. Likewise, for developing equilibrium equations, Newton's second law was taken into account. Besides, in another research work Third-order Shear Deformation Theory (TSDT) was investigated to interpret the STL of the laminated composite cylindrical shell in the presence of external flow. The notable achievement of their work was applying higher order shear deformation theory by expanding the displacement filed as cubic order of thickness coordinate to offering the more precise result in comparison with FSDT, particularly in thick shells.

In most of the last literatures survived above, although Sound Transmission Loss (STL) across various types of the shells have been discussed, there is no investigation at multi objective optimization of sound transmission through the laminated composite cylindrical shell with sandwiching a layer of porous material as an intermediate layer. However, it is essential to indicate the fact that although both of the Full method as well as the simplified one are applicable of modeling the porous material, it should be noted that where the STL problems through these shells is being investigated, these methods appear not to be effective to derive the equations. Thus, the authors have used the extended Full method by considering the equations of porous material in three kinds of the wave propagation based on Biot's theory into such structures employing First order Shear Deformation Theory (FSDT). In the next step, in order to satisfy the accuracy of the present formulation, several comparisons are made between the present study and the literature which indicates an excellent agreement. Eventually, multi objective optimization is used to minimize the weight and maximize the STL at the center frequencies of the 1/3 octave band in the frequency interval 0 to 10000 by using Non-dominated Sorting Genetic Algorithm (NSGA-II) as the optimization technique. Likewise, to fulfill this end such parameters including ply orientation angles, material and porous types are chosen as design variables. Note that the ply layer thickness as well as number of plies are kept constant.

2. Model description

The specific problem followed in this paper composed of a laminated composite double-walled cylindrical shell lined with porous materials impinged upon an oblique plane sound wave with incident angle γ whose rays are traveling on planes parallel to the x–z plane, as shown in Fig. 1. Due to the interior cavity inside the