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Original scientific paper

FINITE ELEMENT MODELLING OF IMPEDANCE TUBE TEST

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Abstract. *Impedance tubes are used to characterize porous acoustic materials. The report proposes a suitable model for numerical simulations of the test of materials in an impedance tube. Numerical simulations make it possible to generate synthetic data on the acoustic characteristics of the material when varying the parameters in the material model. These data are suitable for using machine learning algorithms as well as for solving inverse problems for identifying the material parameters in the mathematical model. The Johnson-Champoux-Allard model is used in the work, which is suitable for a wide class of porous acoustic materials.*

Key words: *impedance tube, finite element, acoustic parameters, Johnson-Champoux-Allard model*

1. INTRODUCTION

The creation of new materials intended for sound insulation and noise reduction is connected with their characterization. An impedance tube test can be used to determine the main acoustic material parameters. Usually, these materials are porous. Their characterization is related to the determination of specific material parameters. One possible way to determine these is to use impedance tube test results and numerical simulation of this test. The aim of the present work is to propose an adequate model for numerical simulation with the finite element method.

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2. MATHEMATICAL MODEL

The fluid-structure interaction mathematical model is used to model the impedance tube experiment. In acoustic fluid-structure interaction problems, both the acoustic wave equation and the structural equation need to be coupled to each other [1]. For fluid structure interaction problems, the acoustic and structural matrices are coupled using the following equations.

The load acting on the surface of the fluid cavity by motion of structure is given by:

$$\left[F_f\right]=\rho[R]\{\ddot{u}\} \tag{1}$$

where subscripts s, f are denote structure and fluid, ρ is a density and u displacement vector. The coupling matrix is denoted as:

$$[R]=\oint_S\left[N_f\right]^T\left[N_S\right]dS \tag{2}$$

where $N_f\,, N_s$ are shape functions for fluid and the structural surface of the coupled interface.

The coupled acoustic equation is:

$$\left[M_f\right]\{\ddot{p}\}+\left[C_f\right]\{\dot{p}\}+\left[K_f\right]\{p\}=-\rho[R]\{\ddot{u}\} \tag{3}$$

The load applied to the structure surface by the fluid is given by

$$\left[F_S\right]=[R]^T\{p\} \tag{4}$$

Dynamic equation of structure becomes,

$$\left[M_S\right]\{\ddot{u}\}+\left[C_S\right]\{\dot{u}\}+\left[K_S\right]\{u\}=\left\{R_S\right\}+[R]^T\{p\} \tag{5}$$

Thus, the coupled equation is:

$$\begin{bmatrix} M_S & 0 \\ \rho[R] & M_f \end{bmatrix}\begin{Bmatrix} \ddot{u} \\ \ddot{p} \end{Bmatrix}+\begin{bmatrix} C_S & 0 \\ 0 & C_f \end{bmatrix}\begin{Bmatrix} \dot{u} \\ \dot{p} \end{Bmatrix}+\begin{bmatrix} K_S & [R]^T \\ 0 & K_f \end{bmatrix}\begin{Bmatrix} u \\ p \end{Bmatrix}=\begin{Bmatrix} F_S \\ 0 \end{Bmatrix} \tag{6}$$

where:

p is pressure;
$[M_f]$ is the mass matrix for fluid;
$[C_f]$ is the damping matrix for fluid;
$[K_f]$ is the stiffness matrix for fluid;
$\{F_f\}$ is the acoustic load vector;
$[N_f]$shape function related to the fluid;
$[R]$ is the coupling matrix;
$[M_c]$ is the mass matrix for the structure;
$[C_s]$ is the damping matrix for structure;
$[K_s]$ is the stiffness matrix for structure;
$\{F_s\}$ is the structural load vector.

3. FINITE ELEMENT SIMULATION OF IMPEDANCE TUBE TEST

The Finite element model is based on fluid-structure interaction problem [2]. The matrix formulation is given in section 2.

3.1. Geometry model

The geometric mode ANSYS software [3] based on the finite element method has been used to develop the numerical simulation. In ANSYS there are two specific acoustic elements that correspond to the impedance of the tube with which the test of the acoustic material is carried out. The acoustic material is modeled as a disk with a diameter of 100 mm and a thickness of 10 mm. The wedge between the eastern sample and the source of sound impact is a cylinder with a diameter of 100mm and a height of 500mm. The geometry model of the boundary value problem is shown in Fig. 1.

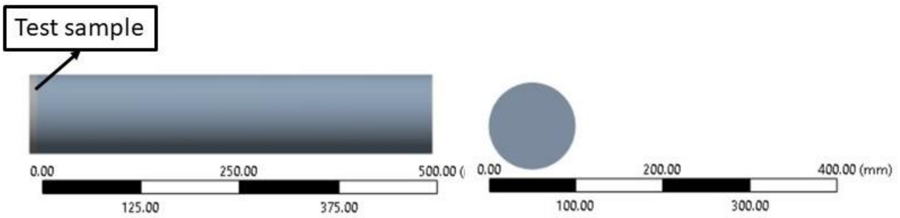

Fig. 1 The geometry model of the boundary value problem

In a vibro-acoustic analysis, typically are used two main physics regions:

- Structural Region: This region involves solid structures that can vibrate. It includes the material properties, boundary conditions, and any external forces or excitations applied to the structure. The structural region is responsible for capturing the mechanical vibrations of the solid components.
- Acoustic Region: This region involves the fluid medium (usually air) through which sound waves propagate. It includes the acoustic properties of the fluid, such as density and speed of sound, as well as boundary conditions like impedance or radiation boundaries. The acoustic region captures the propagation of sound waves generated by the vibrating structure. The interaction between these two regions is crucial in vibroacoustic analysis. The vibrations from the structural region generate sound waves in the acoustic region, and these sound waves can, in turn, affect the vibrations of the structure.

3.2. Material model

The material porous acoustic sample is based on The Johnson-Champoux-Allard (JCA) [4] The Johnson-Champoux-Allard (JCA) model is a mathematical model that describes the acoustical properties of **air-filled porous materials** using parameters such as flow resistivity, porosity, tortuosity, and two characteristic lengths. The JCA model uses the following five parameters to describe the sound propagation through a porous sound absorbing material: the flow resistivity Ξ ; the porosity Φ ; ,the tortuosity $\alpha\infty$; the thermal and viscous characteristic lengths Λ,Λ'.

ANSYS software based on the finite element method has been used to develop the numerical simulation. In ANSYS there are two specific acoustic elements are used.

The boundary value problem is modeled with 73190 nodes and 18262 elements. (Fig. 2). The governing equation for acoustics, namely the 3-D wave equation, has been discretized taking into account the coupling of acoustic pressure and structural motion at the interface. The element node has four degrees of freedom per node: translations in the nodal x, y and z directions, and pressure.

The FLUID220 FE is used. The FLUID220 is a higher-order 3-D 20-node solid element that exhibits quadratic pressure behavior. The frequency interval was prescribed [0 – 1600 Hz].

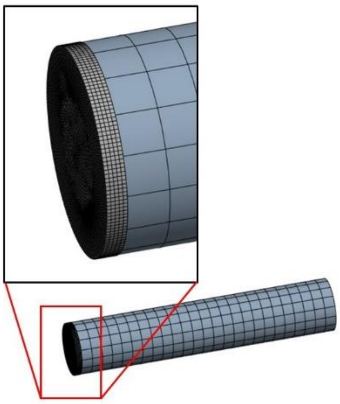

Fig. 2 The FE model of boundary value problem for impedance tube

Boundary conditions are shown in Fig. 3.

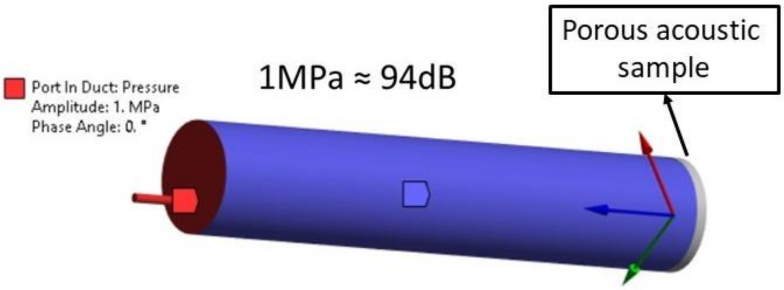

Fig. 3 Boundary conditions prescribed on boundary value problem for impedance tube

3.4. Numerical results

An acoustic analysis calculates either the propagation properties of pure acoustic waves in the given environment or the coupled acoustic structural interaction (FSI) As a result of the numerical solution the sound absorption coefficient can be obtained (Fig. 4).

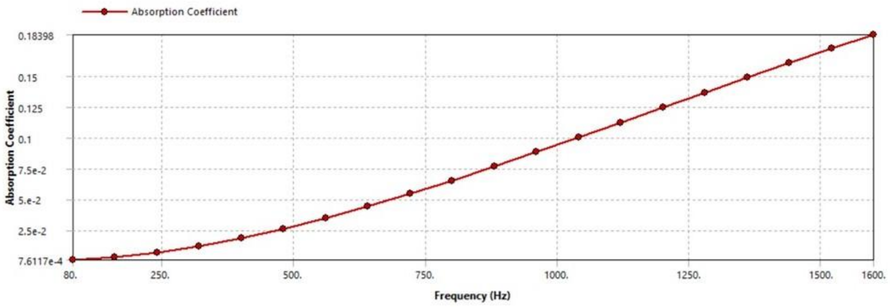

Fig. 4 Absorption coefficient in frequency interval [0 – 1600 Hz]

4. CONCLUSION

A finite element computational model was proposed for the numerical simulation of the impedance tube experiment. The model can be parameterized both in terms of material parameters and also in terms of geometric parameters. This makes it possible to obtain a series of numerical results for the acoustic parameters of the model. These solutions will be used within the G6006 project for the development of machine learning algorithms designed for the identification of model parameters describing the created acoustic porous materials.

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