# FINITE ELEMENT ANALYSIS OF AN EARMUFF-EARCANAL SYSTEM

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## 1. INTRODUCTION

The use of earmuffs is one of the useful ways to protect against hearing loss in environments where noise levels are not controllable within safe limits. Whenever the use of earplugs is impossible or impractical, the use earmuffs provides a means of reducing sound intensity, and in many instances to a degree even greater than that provided by earplugs. Also, earmuffs tend to deliver higher in-field noise protection in many high frequency noise environments than most earplugs.

This research presents the direct coupling of FEM models of an earmuff-like structure and acoustic cavity (air cavity plus ear canal). Vibro-acoustic steady-state and transient responses are predicted for a hearing protection device (HPD, such as an earmuff that attenuates the pressure wave prior to its reception by the eardrum). The modeling of the coupled structure-acoustic-cavity system is important to predict the level of protection achievable for the wearer. Therefore, the FEM technology is essential for the analysis of this kind of problem.

## 1. METHODOLOGY

### 1.1 FEM formulation for the structure

For a general elastic structure, the differential equations governing the motion can be written in the following matrix form as:

$$[M_s]\{\ddot{u}\}+[C_s]\{\dot{u}\}+[K_s]\{u\}=\{F(t)\} \qquad (1)$$

Where $[M_s]$, $[C_s]$ and $[K_s]$ are respectively the mass, damping and stiffness matrix. $\{\ddot{u}\}$, $\{\dot{u}\}$, $\{u\}$ and $\{F\}$ are respectively the nodal acceleration, velocity and load vector.

### 1.2 FEM formulation for the acoustic cavity

The discretization of the pressure-wave equation by the finite element method leads to the following differential system of equations:

$$[M_a]\{\ddot{p}\}+[K_a]\{p\}=\{0\} \qquad (2)$$

Where $[M_a]$ and $[K_a]$ are respectively the fluid mass and stiffness matrix. $\{p\}$ is the nodal pressure vector.

### 1.3 Acoustic fluid-structure coupling

At the interface between the structure and acoustic cavity, the boundary conditions must satisfy the compatibility and equilibrium coupling conditions. First, he displacement of the structure must coincide with the displacement of the acoustic particle. Secondly, the dynamic equilibrium condition requires that the normal force produced by the vibrating structure at the interface must be to the total acoustic pressure force:

$$n.\nabla p=-\rho n.\{\ddot{u}\} \qquad (3)$$

The governing finite element matrix equations for the coupled structure-cavity system are then written as (time-dependent solutions):

$$\begin{bmatrix} M_s & 0 \\ \rho R^T & M_a \end{bmatrix}\begin{Bmatrix} \ddot{u} \\ \ddot{p} \end{Bmatrix}+\begin{bmatrix} C_s & 0 \\ 0 & 0 \end{bmatrix}\begin{Bmatrix} \dot{u} \\ \dot{p} \end{Bmatrix}+\begin{bmatrix} K_s & R \\ 0 & K_a \end{bmatrix}\begin{Bmatrix} u \\ p \end{Bmatrix}=\begin{Bmatrix} F(t) \\ 0 \end{Bmatrix} \qquad (4)$$

With the assumption of time-harmonic evolution of the system (steady case), the governing equation (4) takes the following form in the frequency domain:

$$\begin{bmatrix} -\omega^2 M_s + j\omega C_s + K_s & R \\ -\omega^2 \rho R^T & -\omega^2 M_a + K_a \end{bmatrix}\begin{Bmatrix} \bar{u} \\ \bar{p} \end{Bmatrix}=\begin{Bmatrix} F \\ 0 \end{Bmatrix} \qquad (5)$$

Where $\omega$ is the pulsation of the load.

## 2. ANALYSIS OF AN EARMUFF-EARCANAL SYSTEM

The earmuff normally consists of a plastic-shell earcup with a cushion sealing it to the flesh around the ear. When the earmuff is worn, an air cavity is created within the ear-cup. This cavity extend into the ear-canal up to the eardrum which represented by a specific impedance (Z= 5026.55Pa.s/m). An acoustic pressure wave impinges on the outside surface of the ear-cup, causing it to vibrate. For the earmuff-earcanal system modelled [Vergara(2002)], the dimensions and the physical parameters are reported in Fig. 1 and Table 1..

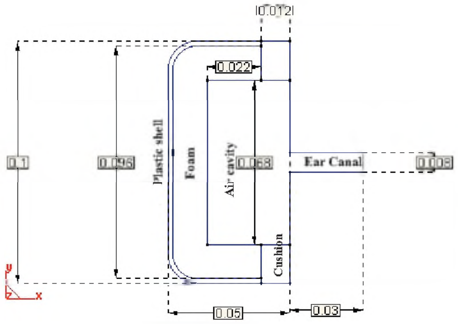

Fig.1. Dimensions in meters of the earmuff-earcanal system studied.

### 2.1 Transient response

A triangular pressure impulse simulating gun shot is applied uniformly over the earmuff shell to get the transient response at the eardrum. The assumed pulse shape, presented in Fig. 2, has a rising time of 1 ms and a duration of 3.0 ms. The maximum and the minimum pressure are respectively set to 1130 Pa and -100 Pa. The resulting FEM transient pressure history from the FEM at the eardrum is shown in Fig. 2.

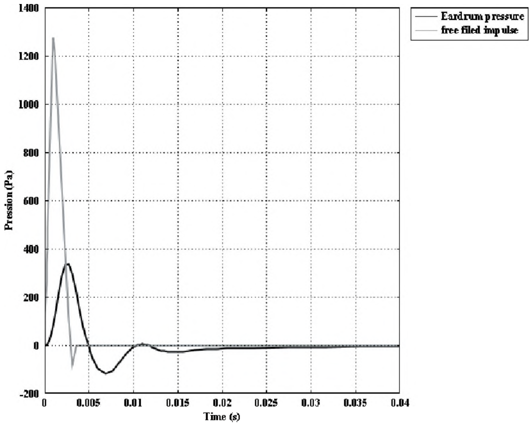

Fig.2 Pressure vs time histories for the free field excitation and FEM predicted tympanic pressure.

The predicted FEM attenuation provided by the studied earmuff is equal to 12.00 dB which is close to 12.6 dB as measured by Vergara & al [Vergara (2002))]

### 2.2 Steady state response

The internal pressure level response is predicted at the eardrum over the frequency range of 25Hz to 5kHz (Fig.3). The attenuation of the earmuff is weak around the first resonant 140 Hz of the coupled system. This frequency is very close to the resonant frequency of the structure 141 Hz.

Table 1. Physical properties.

| material | Young modulus (Pa) | Poisson coefficient | Density (kg/m3) | Sound celerity (m/s) |
|---|---|---|---|---|
| Plastic | $1.94\ 10^{+9}$ | 0.38 | 1200 | |
| Foam | $3.34\ 10^{+7}$ | 0.33 | 320 | |
| Rubber | $2.5\ 10^{+5}$ | 0.49 | 1522 | |
| Air | | | 1.21 | 343 |

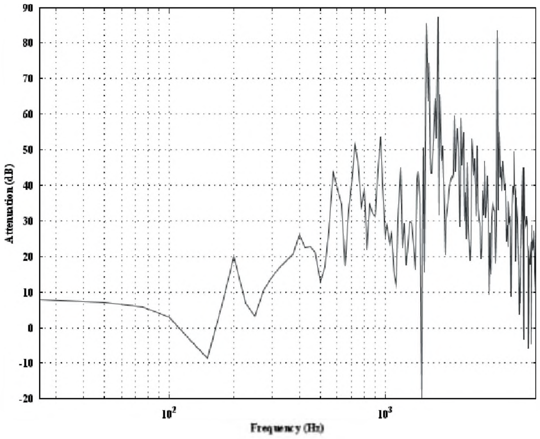

Fig. 3.Steady state response of earmuff-earcanal system for a uniform external pressure.

## 3. CONCLUSION

A FEM model has been developed to predict the steady-state and transient responses for an earmuff-earcanal system. Good agreement between the model and available experimental data for the configuration studied has been obtained.

## REFERENCES

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