Determination of the Noise Attenuation of Hearing Protectors by Numerical Modeling of the Outer Ear

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ABSTRACT: This paper addresses the important practical issues of hearing protectors used in industry to protect the workers from high noise levels. Comments on the difficulties in measuring hearing protectors noise attenuation is discussed. A new work is presented on the numerical modeling of the outer ear canal as a straight tub, considering eardrum acoustic impedance, using finite elements (FEM), for the quantification of noise attenuation is presented. This numerical model can serve as a quick and low cost tool for the optimization of the protector project and the investigation of the effect of different parameters such as protector insertion, effect of leakage, materials, and others on the protector noise attenuation.

INTRODUCTION

The Real-Ear-Attenuation-at-Threshold (REAT) is the most commonly worldwide procedure for measurement of the noise attenuation on human subjects (ISO 4869[1], ANSI S12.6/97[2]). A complete test for a single model hearing protector requires between 10 and 20 qualified subjects, two to three times testing each. The subjects have to be qualified prior to the test in audiometric facilities. These conditions result in a long duration and expensive tests, which usually take more that 25 hours and cost about US$ 1,500.00 for each type. Alternative methods should be explored to quantify the hearing protector attenuation. It is also necessary to use a low cost and quick methods for the manufacturers to investigate the effect of the protector parameters, such as geometrical variation of the human pinna, ear canal, HPD type and size, the effect of wearing and fitting conditions, the effect of design parameters (materials, dimension tolerance, geometrical form, etc.). Numerical modeling methods, such as Finite Element Method (FEM) and Boundary Element method (BEM) can be used to give accurate, rapid and low cost results.

NUMERICAL MODELLING FOR HPD NOISE ATTENUATION

A reliable model for the frequency range up to 20KHz has to consider at least the ear canal and ear drum acoustics impedance (Shaw[3]). No published literature exists describing the application of numerical methods (FEM and BEM) to completely model the human ear, except works at North Carolina State University [4, 5, 6],where the outer ear canal is modeled with the BEM, considering elastic and viscoelastc plugs. In this paper the foam plug type-hearing protector is modeled as a porous material. Limited Preliminary results are presented in this paper for the modeling of the ear canal as a straight tube with the ear drum acoustic impedance with and without the plug, using FEM. A porous foam earplug can be modeled numerically considering its materials as locally reacting with only one longitudinal wave propagation. Another more representative model developed by Biot[7], which considers the propagation of three waves in porous materials (two longitudinal and one transverse). In this paper, analytical and numerical models are presented, for a one-dimensional straight tube model with eardrum impedance, representing the outer ear.

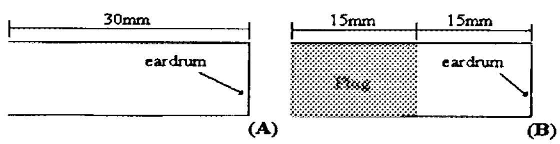

Figure 1: One-dimensional model for the outer ear (A) without and (B) with earplug

Consider straight hard walls tube excited by incident sound wave at the open end (see fig. 1(A)) and with the acoustic impedance of the eardrum at the other end. The acoustic pressure on the eardrum P2 from the total incident sound pressure at the entrance P1 is given by;

$$P2/P1 = Z/[Z\cos(kL)+i(\rho c/S)\sin(kL)] \qquad (1)$$

Where: Z is the eardrum acoustic impedance ; L is the tube length (30 mm); and ρc is the air impedance.

Figure 2 show the comparison of the SPL difference at the eardrum and tube entrance, given by equation (1), and by FEM. These figures show that the FEM for this simple case gives very similar results as the analytical model in closed form solution.

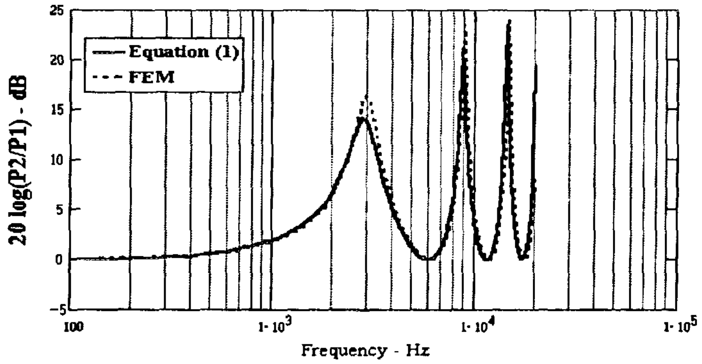

Figure 2: Eardrum SPL response for open one-dimensional model

The above model can be extended to considered plugged tube, as shown in figure 1(B). The plug characteristics use are: Material Density = 98 [Kg/m^3], Sound velocity = 320 [m/s]; Flow resistance = 25000 [Kg/m^2.s]; Structure factor = 7.9; Porosity = 0.9. The calculated results for the insertion loss by FEM are shown in Figure 3.

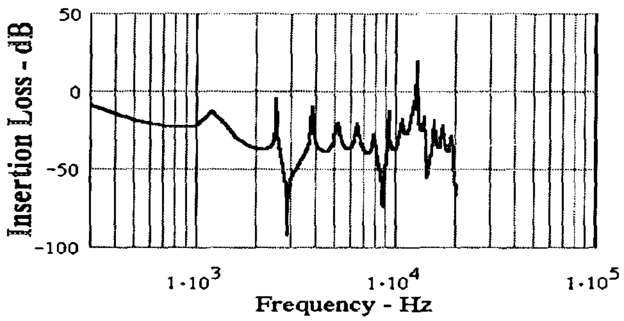

Figure 3: Insertion loss of foam ear plug

CONCLUSIONS

The problem of quantification of the noise attenuation of hearing protectors is discussed. The conventional subjective test involves a large number of subjects, costly instrumentation, physical installations and long-term testing. Numerical modeling using finite element method may be considered a quick and low- cost tool for the optimization of the hearing protector devices and can shed some light on the acoustic behavior of the outer ear and ear canal.

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