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INFLUENCE OF EXTERNAL EAR CANAL ABSORPTION ON MECHANICS OF HEARING

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Summary: *The analysis of mechanics of the normal human ear and of the is performed. The creation of the finite element model of the middle ear is described. The model of the normal ear includes external ear canal, tympanic membrane, ossicle chain with joints to oval window in the enter of cochley. The amplitude of the stapes footplate velocity and the amplitude of pressure excitations in external ear canal and in middle ear space were evaluated for different values of external ear canal absorption.*

1. Introduction

Human ear is very complex system which converts an acoustics signals from outer air environment into electrical signals which transfer sound information into the brain. In the case of air conduction the sound propagate through external ear canal where the sound waves are converted into mechanical vibrations of tympanic membrane. Consequently the vibrations of tympanic membrane cause moving of ear ossicles (maleus, incus, stapes) which excite pressure travelling waves in cochlea. These pressure travelling waves excite basilar membrane at what sense organ is allocated.

Every parts of human ear share in global transfer function. The goal of this work was determination of human outer ear canal absorption on mechanics of hearing. Interaction between fluid systems of outer ear canal, middle ear space, cochlear spaces and structural systems of tympanic membrane and ossicular chain was solved. The velocity of stapes movement and pressure amplitudes in outer ear canal and in middle ear space was mainly observed. Finite element system Ansys was used for solving of this problem.

2. Creation of the FEM model

The model oh the human ear was created in finite element system Ansys. The model contains fluid spaces of outer and middle ear, which are apart divided by tympanic membrane. Ossicular Chain (it is malleus, incus and stapes) is fixed to the tympanic membrane. The stapes is fixed by annular ligament to oval window. The ossicular chain is also fixed by ligaments and muscles to wall of middle ear space (Figure 1). The Model of the fluid spaces of outer and middle ear is created through the use of data from computer tomography. The Model of tympanic membrane was modelled after the data from literature (Sedláček 1956, Wada 1997, Ferrazinni 2003) and the model of malleus, incus and stapes was created by dimensioning of real human ossicles.

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The model of human ear also includes the cochlea of inner ear. The cochlea consists of fluid spaces of scala vestibuli, scala media and scala tympani. These fluid spaces are apart separated by basilar and Reissner's membranes. The model of cochlea was created after the data from literature (Békésy 1960, Syka 1981).

Final model comprehend 13565 elements SOLID45, 50188 elements FLUID30 with four degrees of freedom in nodes, 66352 elements FLUID30 with one degree of freedom in nodes and 10 elements LINK8. The transfer functions of single parts of human ear and their interactions are possible to analyze on this model. More information about creation of this model is possible to find in articles (Pellant 2004, Dušek 2005).

Complete model of human ear is showed in figure 2 (The structural parts of middle and inner ear are marked by red color).

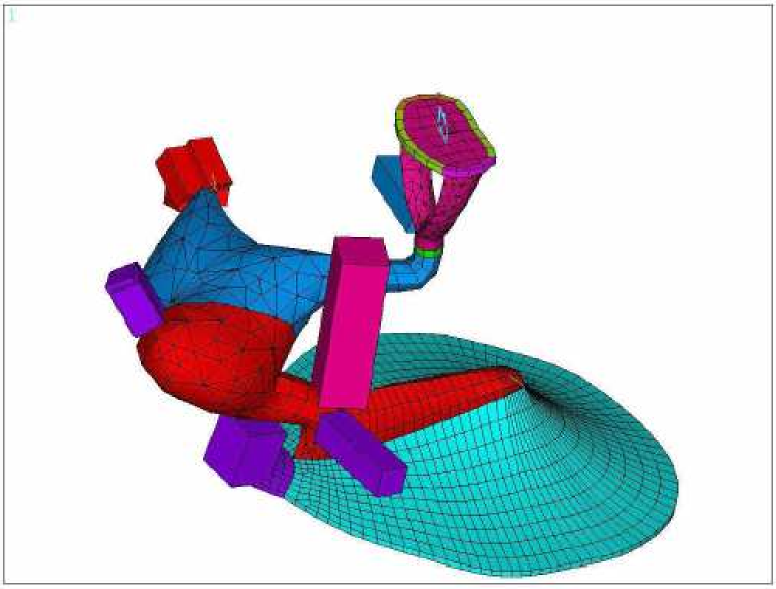

Figure 1: Structural part of middle ear (it is tympanic membrane, malleus, incus, stapes, ligaments and muscles)

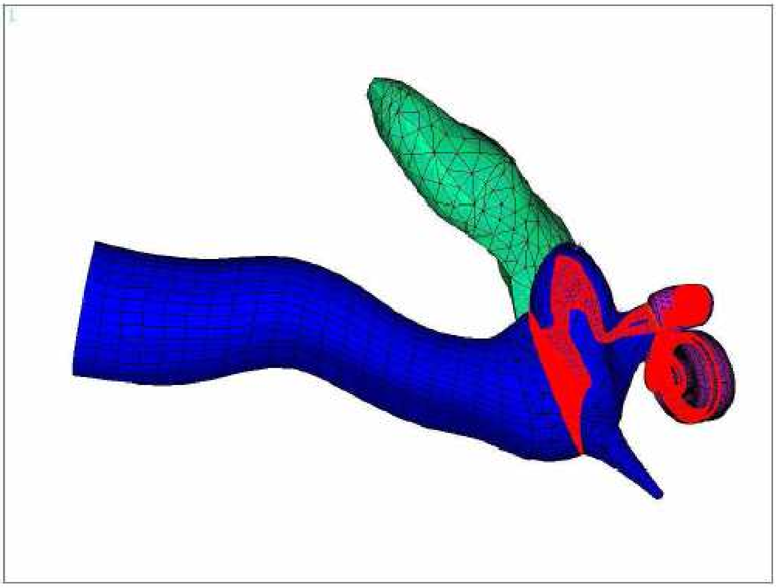

Figure 2: Complete model of human ear

3. Results of modal analysis

Modal analysis was solved for structural and fluid parts separately by reason of its better identification of natural frequencies. Only Fluid spaces of outer ear canal, fluid spaces of middle ear and structural parts of middle ear (It is tympanic membrane with malleus, incus, stapes, ligaments and muscles) were solved. The fluids spaces (scala vestibuli, scala media, scala tympani) and structural parts (basilar and Reissner's membranes and sacculus) of inner ear were not solved by reason of amount frequencies in monitored frequency range.

The figures 3 and 4 show first two mode shapes of fluid space of outer ear canal. Mode shape of outer ear canal correspondent to eigenfrequency 2896Hz is showed in figure 3 and mode shape of outer ear canal correspondent to eigenfrequency 8126Hz is showed in figure4. The figures 5 and 6 show first two mode shapes of fluid space in middle ear. Mode shape of middle ear fluid space correspondent to eigenfrequency 2746Hz is showed in figure 5 and mode shape of middle ear fluid space correspondent to eigenfrequency 10289Hz is showed in figure 6. The figures 7 and 8 show first two mode shapes of structural part of middle ear correspondent to eigenfrequencies 794Hz and 1108Hz. The eigenfrequencies of fluid space of outer ear and middle ear and eigenfrequencies of structural part of middle ear are mention also in table 1.

Mode	Outer ear canal	Middle ear space	Structural part of middle ear
1	2896Hz	2746Hz	794
2	8126Hz	10289Hz	1108
3	-	-	1324
4	-	-	1413
5	-	-	1585
6	-	-	1619

Table 1: Eigenfrequencies of single part of human ear

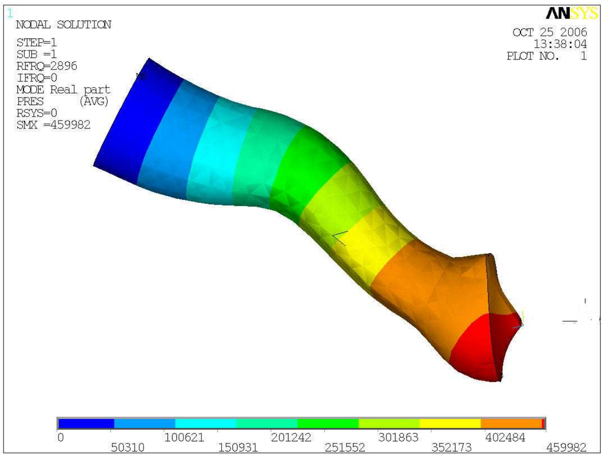

Figure 3: Results from modal analysis of outer ear canal for eigenfrequency 2896Hz

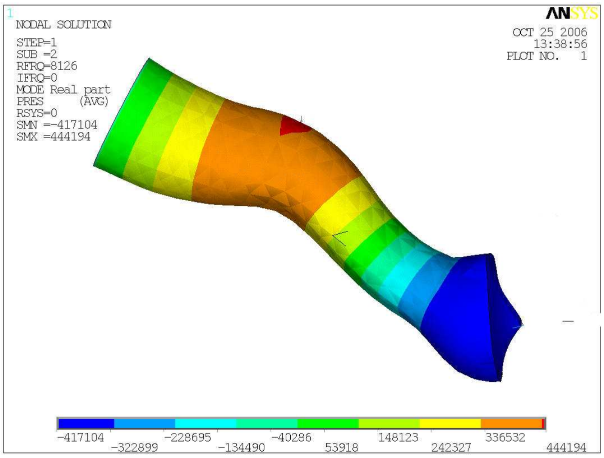

Figure 4: Results from modal analysis of outer ear canal for eigenfrequency 8126Hz

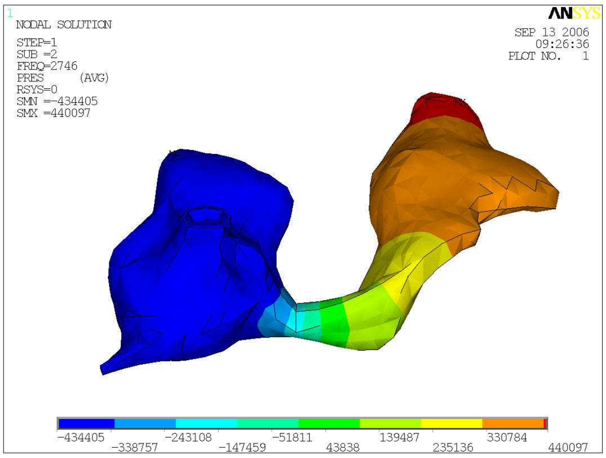

Figure 5: Results from modal analysis of middle ear space for eigenfrequency 2746Hz

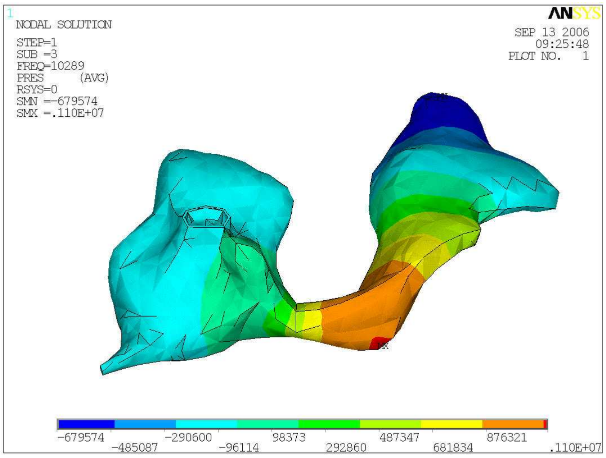

Figure 6: Results from modal analysis of middle ear space for eigenfrequency 10289Hz

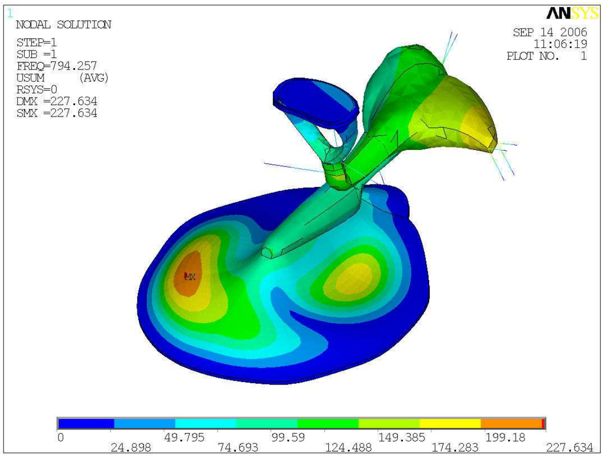

Figure 7: Results from modal analysis of middle ear structures for eigenfrequency 794Hz

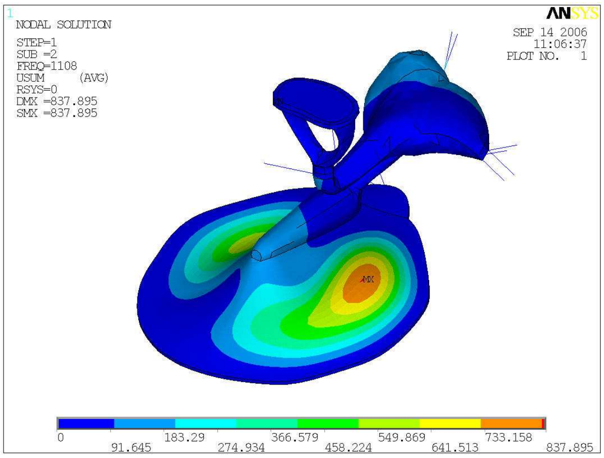

Figure 8: Results from modal analysis of middle ear structures for eigenfrequency 1108Hz

4. Results of harmonic analysis

Harmonic analysis was solved for parametrical computation of outer ear canal wall absorption (with values MU=0,005; MU=0,05 a MU=0,01). Amplitude of acoustic pressure in outer ear canal is displayed in figure 9. There are four peaks on the curve of the amplitude of pressure. After comparison results of modal analysis and transfer function of pressure in outer ear canal, it is evident that first maximum (about 1,3kHz) on transfer function corresponds to eigenfrequency of structural part of middle ear. Second maximum (about 3kHz) on transfer function corresponds to first eigenfrequency of outer ear canal. Third maximum (about 4kHz) on transfer function corresponds to eigenfrequency of fluid middle ear space. Fourth maximum (about 8Hz) on transfer function corresponds to second eigenfrequency of outer ear canal.

Amplitude of acoustic pressure in middle ear space near stapes footplate is displayed in figure 10. Again there are four peaks on the curve of the amplitude of pressure. Both of these figures clearly show that increasing of outer ear canal wall absorption faces to decrease of maximal amplitude of acoustic pressure mainly on frequencies that corresponds to eigenfrequency of outer ear canal and middle ear space, influence of outer ear absorption on other frequencies is not marked.

Amplitude of the stapes footplate velocity is showed in figure 11. There are three peaks on the curve of the stapes velocity curve. The first maximum (about 1,3kHz) on transfer function corresponds to eigenfrequency of structural part of middle ear. Second maximum (about 3,5kHz) on transfer function corresponds to first eigenfrequency and to eigenfrequency of fluid middle ear space. The third maximum (about 8Hz) on transfer function corresponds to second eigenfrequency of outer ear canal.

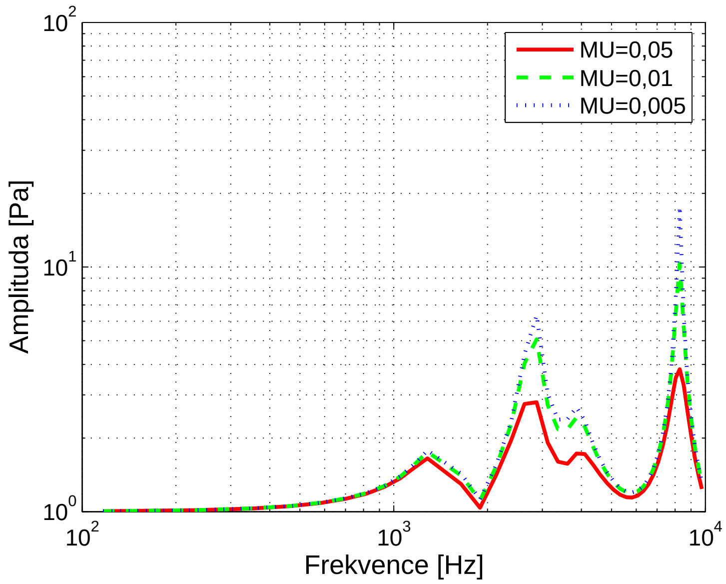

Figure 9: Amplitude of acoustic pressure in outer ear canal

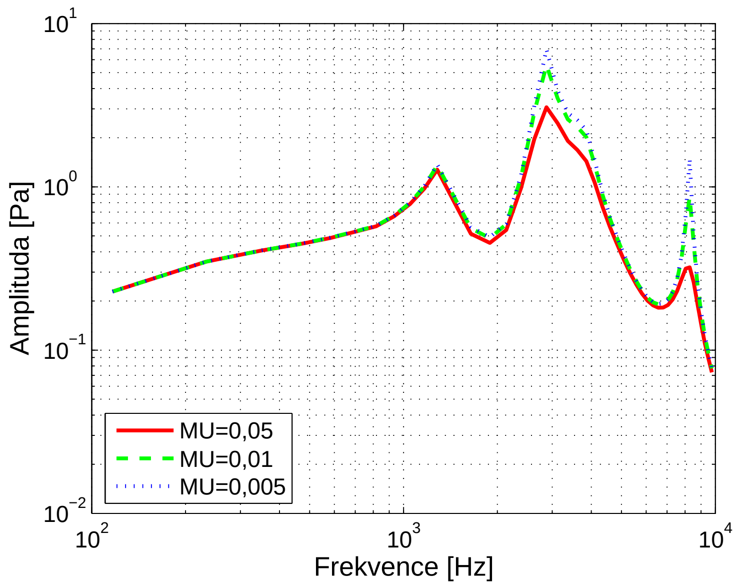

Figure 10: Amplitude of acoustic pressure in middle ear space

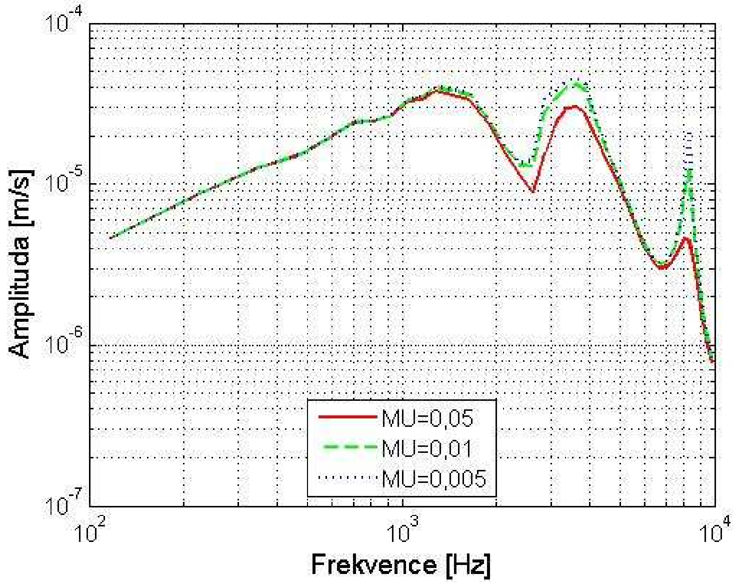

Figure 11: Amplitude of stapes footplate velocity

5. Conclusion

Mathematical simulation shows that influence of outer ear canal wall absorption on transfer function of human ear takes efect just on the frequencies which correspondent to eigenfrequencies of outer ear canal (2,9kHz and 8,2kHz). Increase of the outer ear canal wall absorption causes decrease of amplitude of acoustic pressure in outer ear canal and in middle ear space and it also causes decrease of amplitude of stapes footplate velocity.

6. References

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