Chapter 1

Introduction

Animals have receptors adapted to vibration transmitted through the surrounding medium. Fish have an ability to hear or perceive vibration of surrounding water by means of the lateral line organ. The highly developed vertebrates which live temporarily or permanently on land have to hear air conducted sound; consequently, they must have developed receptors to profit by the vibration of air, because it is necessary that air vibrations are introduced from outside of the body to the inner ear fluid.

The middle ear of mammals are remarkably different from those of other vertebrates in that the malleus, incus, tensor tympani and stapedius muscles appear. Morover, it goes without saying they have developed cochlear turnings. Mammals usually have large auricles and long external auditory meatus. therefore, their tympanic membranes are found embedded further from the external surface of the head in comparison to their situ in birds and, specifically, in large mammals.

In order to go from the general point of view of the mammals to a more especific field it is necessary to say that, although it is interesting to understand the behavior of the mammals hearing in general, the last goal is to get a good knowledge of the human hearing. So, in the next point, more expecifical details about the human hearing are shown.

1.1 Hearing on humans

Airborne sound are pressure fluctuations p superposed to the static pressure p_{stat} which can be sensed by humans in a highly diynamical process in the range between 16 Hz and 16 kHz. The function of pinna, ear canal and middle ear is the transfer of sound events in the free field to the inner ear. In air conduction the sound pressure p is transformed by the ear drum into mechanical vibrations of ear drum and ossicular chain consisting of malleus, incus and stapes. The annular ring seals the tympanon from the liquid filled inner ear, a very complex system with the organ of equilibrium and organ of Corti for hearing sensation in the cochlea. This is a convolute tube with 2.5 windings and 3 internal scales: scala vestibuli, in which oval window of the stapes is situated; scala tympani connected via the helicotrema with scala vestibuli and via a membrane in the round window with the tympanon, and scala media or ductus cochlearis.

Scala vestibuli and scala tympani are filled with perilymphe, scala media contains endolymphe. the organ of Corti is located between scala media and scala tympani on the basilar membrane and consists of over 12000 outer hair cells arranged in three rows, one row of inner hair cells and several kinds of pillar cells. the motion of fluid and of basilar membrane causes a deformation of stereocilia of the hair cells which opens ion channels and start a chemical process. This affects an electrical sensation of auditory nerves with a voltage of up to 80 mV and activates the cells itself to contract which amplifies their stimulation (cite 1). Due to this fact the hearing potential is over an extremely wide range starting from the hearing threshold around $p_0 = 2 \cdot 10^{-5}$ Pa (0 dB), normal loudness of speaking around $p = 2 \cdot 10^{-2}$ Pa (60 dB), threshold of pain $p = 2 \cdot 10^{1}$ Pa (120 dB) and transient loads e.g from firearms up to $p = 2 \cdot 10^{3}$ Pa (160 dB). In bone conduction the hair cells are excited by the structural vibrations of temporal bone.

1.2 Why Guinea Pigs?

In order to work with human middle ear models the main problem is their validation. Therefore, a different approach is necessary. The best solution would be the chimpanzee since the middle ear of this animal is very similar to the human one. However, they are very expensive as well as there are many dificulties in order to work with these animal and taking in count the high number of measuremtns which are necessary, this is not an efficient election. So, there are several options in order to go through this problem: chinchilla, guinea pigs, rats. In this work the guinea pig is choosen because of, from a experimental point of view, they are pretty cheap as well as the regulations about them are not so rigid. There are many differents between human and guinea pig (e.g.: their size) but in order to get an idea about the hearing process, not only in the human case but in mammals, this is a reasonable approach.

1.3 Approach to the problem

Due to the different sound transmissions to the inner ear and the different mechanisms of its excitation like structural vibrations of the skull, mechanical vibrations of the ossicular chain in the middle ear, air borne sound in the tympanic cavity, there are different modeling techniques to describe these mechanisms.

Classical models are often based on electric circuits using electro-acoustical and electro-mechanical analogies. These models are mostly dealing with scalar entities in a global sense and do not describe the local three-dimensional dynamical behavior of the ossicles.

Mechanical models of the tympanic membrane using the Finite Element approach were published by many authors. The ossicles have been included by some authors in their Finite Element models, also. However, this approach leads to large systems with a huge number of parameters.

The application of Multibody Systems approach[8] was proposed in [2] and this is the base of the models considered later on.

1.4 Summary of the work

It was the main objetive of this work is to build a guinea pig middle ear model using the multibody system techniques. However, several points were got as well: it was developed a procedure to estimate the mechanical properties of the ossicles and it was done a sensitivity analysis of influence of several parameters in the frequency response of the system.

The chapter 2 describes briefly the anatomy of the guinea pig middle ear. In this chapter, number and morphology of middle ear muscles and ossicles are described.

In the chapter 3 a overview of the mathematical concepts behind the multibody system techniques and the analysis in the frequency domain is made..

Chapter 4 is about the description of the model which was built. This chapter describes the number and characteristics of the bodies and how their mechanical properties were calculated; the number and kind of restrictions of the system; the generalized coordinates that were used and the forces applied to the model.

The chapter 5 shows all the results obtained from the simulations. These results are a sensitivity analysis to see the influence of certain parameters of the model in the frequency response of the system and a later adjustment process in order to fit the model with the experimental results available. Thus, the frequency response of the system was got as well as the nine first eigenfrequencies. The frequency response was compared to the experimental results and an acceptable agreement were got.

In the chapter 6 it is possible to see a summary of the word which it has been done as well as several conclusions from the obtained results. Differents line for a future work are proposed as well.