EMANATIONS FROM RESIDUUM OSCILLATIONS IN HUMAN AUDITORY SYSTEM

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Abstract*— The human auditory system is divided into three main parts: outer, middle and inner auditory system. The auditory system is mainly responsible for hearing and balance. The Cochlea, which is present in the inner auditory system, consists of Basilar Membrane, Organ of Corti, OHC and IHC together execute the hearing mechanism. Otoacoustic Emissions are inaudible sounds which come out from the inner auditory system. These are produced due to Cochlear amplification wherein OHCs play an important role by providing electro-mechanical positive feedback. OAEs are mainly used for diagnosis of hearing sensitivity in new-born babies and adults. They are not produced for persons having hearing disabilities more than 25 -30 dB. The OAEs are classified into Spontaneous and Evoked types. The main objective of this project is to generate Transient-Evoked and Sustained-Frequency OAEs by simulating a human inner auditory system model. The basic underlying principle of modeling the human inner auditory system used in this project is Hydrodyamics. Hydrodynamics is the study of motion of incompressible and compressible fluids. The incompressible fluids present inside the cochlea, Endolymph and Perilymph, are responsible for the movement of the BM..

Keyword-OHC,IHC,Baislar Membrane,OAE,Hydrodynamic model

I. INTRODUCTION

The auditory system is the organ responsible for detection of sound. It also aids in balance and body position. The auditory system is the one responsible for processing of sound. Sound is a form of vibration energy that can pass through air, water or any other medium. They are nothing but waves of pressure. The auditory system converts the sound energy into nervous signals that are sensed by the central nervous system. Sound waves are perceived by the brain through the firing of nerve cells in the auditory portion of the central nervous system. The auditory system consists of three main subdivisions. They are outer, middle and inner portions. The outer auditory system consists of the auditory system canal and auditory system drum (tympanic membrane). Sound waves enter the auditory system through the auditory system canal and as a result cause the movement of the tympanic membrane. As a result, the sound energy is translated into mechanical vibrations. Middle acts as a mechanical lever system which consists of malleus, incus and stapes. The arrangement of these three bones is such that the vibrations from the tympanic membrane cause the acceleration of stapes. The to and fro motion of stapes causes pressure changes in the fluids (Perilymph and Endolymph) present in the cochlea which is inside the inner auditory system.

The cochlea performs the function of converting the mechanical vibrations into nerve impulses which is essentially hearing. The main parts of the cochlea are the frequency decomposition layer and also a specialized structure that transmits the acoustic vibrations to nerve fibers. The Basilar Membrane vibrates near its apex for lower frequencies and near its base for higher frequencies. Basilar membrane has two kinds of sensory receptors. The vibrations of the Basilar membrane are amplified by means of one of the sensory receptor,mainly, by OHCs. IHCs perform the conversion of the vibrations into nerve impulses which are finally transmitted to the brain via the eighth cranial nerve. The auditory system includes the vestibular apparatus namely the utricle, saccule, and three semicircular canals. The utricle and saccule uses thin stones and a sticky fluid to stimulate hair cells to detect motion and orientation.The interconnected tube located inside each ear will identify rigid body movement, are situated at 90 degrees to one another and are completely or almost fulled with a fluidic known as Scarpa's fluid.The Scarpa's fluid will lag behind due to inertia and exert pressure. The region of tissue in a cell membrane will deliver a sudden strong urge to an organ of soft nervous tissue contained in the skull of vertebrates that is the coordinating centre of sensation of movement.

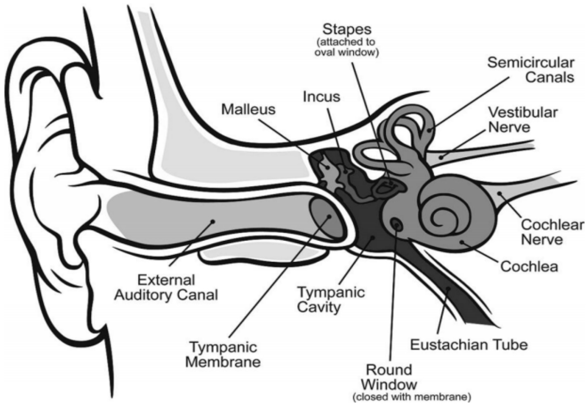


Fig 1. Human Auditory system

II. OAE

Otoacoustic Emissions are inaudible sounds which come out from the inner ear. These are produced due to Cochlear amplification wherein OHCs play an important role by providing electro-mechanical positive feedback. OAEs are mainly used for diagnosis of hearing sensitivity in new-born babies and adults. They are not produced for persons having hearing disabilities more than 25-30 dB. The OAEs are classified into Spontaneous and Evoked types. The Evoked OAEs are further classified into Distortion product, Sustained frequency and Transient Evoked OAEs.

III. Basilar membrane in cochlea Dynamics

Due to the applcation of sinusoidal pressure on the third bone of the middle ear, the oscillation of the BM will bringforth the fact that the wave will be produced in which the medium moves in the direction of propagation of the wave.

The Basilar membrane is intrinsically formed with less densely tensed elastic fibres across the scala media.The thread-like pieces are short and packed tightly in the base of the snail-shell-shaped cochlea near the middle ear.

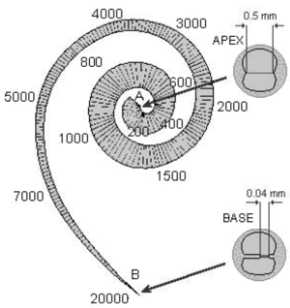


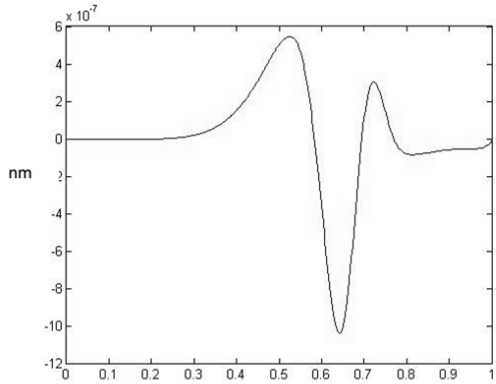
Fig 2 Basilar Membrane in Cochlear Dynamics

IV. Basilar membrane Displacement

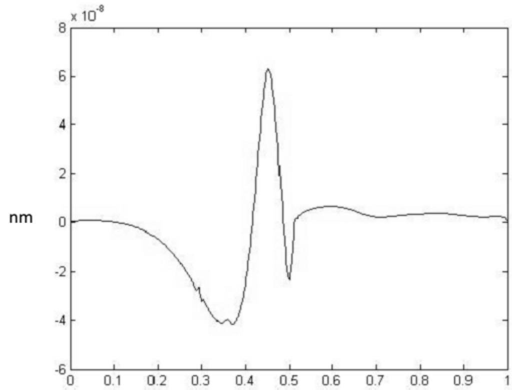
The Basilar Membrane was considered as a longitudinal section and its length was normalized from 0 to 1.

Here, 0 represents the base and 1 represents the apex. For higher frequencies, the hair cells present near the base of the BM whereas for lower frequencies the vibrations occur near its apex.

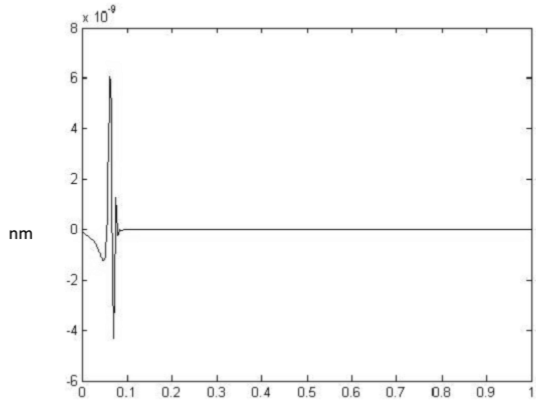
A. For t=15s and freq=25 Hz – graphs were plotted distance Vs Distance in stapes



B. For t=15s and freq=1000 Hz



C. For t=15s and freq=10000 Hz

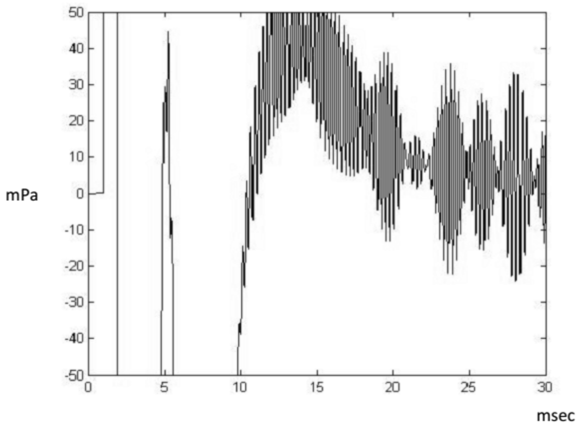


In the above outputs, stapes acceleration in the form of sinusoidal frequencies ranging from 25 Hz to 10 kHz was given to the hydrodynamic model. It was observed that for lower frequencies, such as in the first output, the vibration of BM was concentrated in the range of 0.6-0.7, i.e. near the apex. It was also observed that for higher frequencies, such as 10 kHz, the vibration occurred between 0-0.1, i.e. near base. Hence, true to the characteristic of BM, the vibrations of the hair cells from apex to base were obtained.

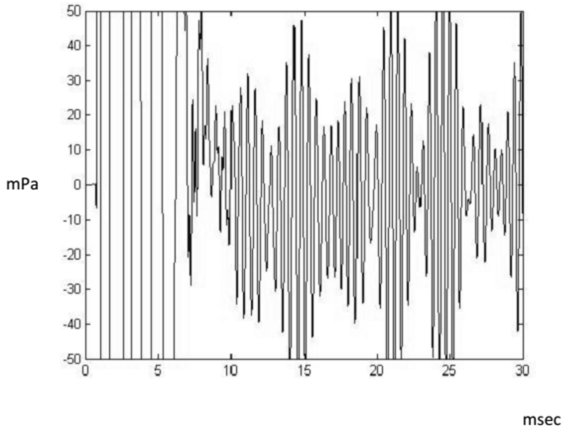
V. OAE IN TERMS OF VESTIBULAR PRESSURE OAE IN TERMS OF VESTIBULAR PRESSURE

The vestibular pressure changes in the fluids present inside the cochlea due to cochlear amplification, which is mainly responsible for the generation of OAEs were obtained for different input signals.

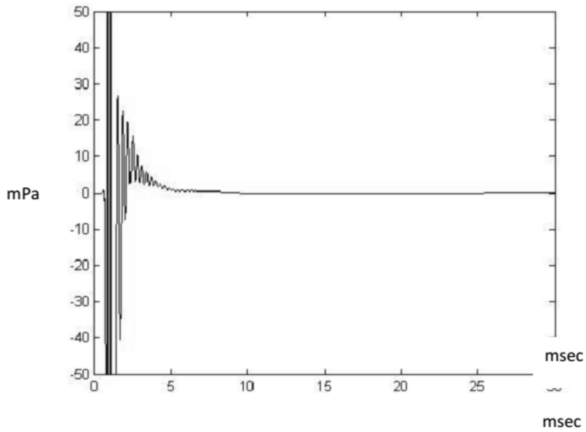
A. For Step input



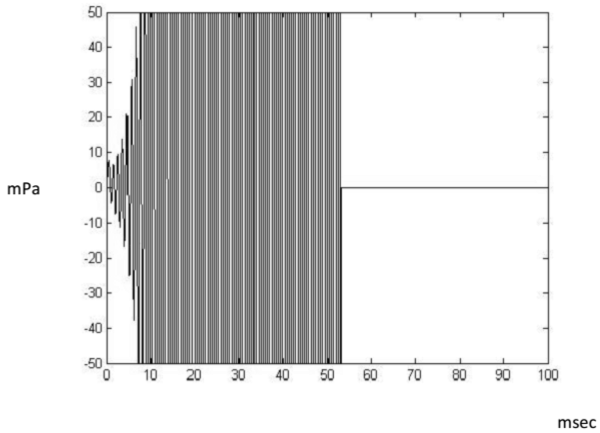
B. For filtered click input



C. For unfiltered click



D. For sinusoidal input



VI. CONCLUSION

The human cochlea was modeled using the principle of hydrodynamics. The basic mechanical properties of the BM like its mass, stiffness, damping, pressure, distance from the stapes etc were expressed through hydrodynamic equations. The Otoacoustic Emissions which are generated when the BM is in motion due to Cochlear Amplification have been simulated in this project as a function of Vestibular pressure changes. Two kinds of Evoked OAEs were generated. By giving step, filtered click and unfiltered click, Transient Evoked OAEs were obtained. When lengthy sinusoidal signals were given, Sustained Frequency Evoked OAEs were obtained.

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