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DESIGN OF A MEMS ARTIFICIAL COCHLEA LIKE AN ARRAY OF RESONATORS

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Abstract: *This paper deal with possibility of using a MEMS technology for design of an artificial cochlea based on an array of resonators. First a simple mathematical model of the array of resonators is presented. A finite element model of an array of resonant beams and results calculated on this model are presented in chapter 3 and 4.*
Key words: *cochlea, MEMS, signal, decomposition, resonators*

1. INTRODUCTION

A cochlea is that part of a human or mammalian ear where a transmission of mechanical signals into electrical signals is made. Also an ability of the signal decomposition into simple frequency components is very important and interesting feature of the cochlea.

The cochlea is basically compound from three fluid spaces (scala vestibuli, scala media and scala tympani) which are divided by two membranes (basilar and Reissner's membranes). The sense cells which transform the mechanical signals into the electrical signals are located just on the basilar membrane. The decomposition of the signals into simple frequency components is made thanks to special modal properties of the basilar membrane.

The basilar membrane has different thickness and width along its length which induce frequency dependent location of maximum amplitude of vibration on the basilar membrane. Low frequency components compound in the signal excite the basilar membrane near its apical end. High frequency components contrariwise excite the basilar membrane near its basal end (Békésy, 1960; Tianying, 2002).

In a case if the sense cells are highly damaged or ill developed only using of a cochlear implant is possibility for return of hearing (Rubinstein, 2004). Today used cochlear implants are compound from two basic parts, an inner part with electrodes which is located inside the head and outer parts with speech processor where similar like in real cochlea a transmission of the signals is made (Wikipedia, 2010). Presently unfortunately don't exist a full implantable artificial cochlea which is able direct in the head to replace the damaged human cochlea.

Today technologies like MEMS (Micro Electro Mechanical Systems) (Gad-el-Hak, 2006) or NEMS (Nano Electro Mechanical Systems) are on the increase. Using of these technologies can lead to design of the full implantable artificial cochlea. A few scientists in the world try to make the artificial cochlea with using of the MEMS technology. Most of them try to design it similar like real cochlea. It means like a membrane with different cross section along its length (Chen et al., 2006; Shintaku, 2010; White & Grosh, 2002). Another possibility is an array of resonant components. Both of the solutions of the problems (continuous membrane or discrete array of resonators) have their advantages and disadvantage. For example the array of resonators has better resolution in a frequency range but the membrane has any behaviour closer to the real basilar membrane (for example similar running of travelling waves and phase characteristics).

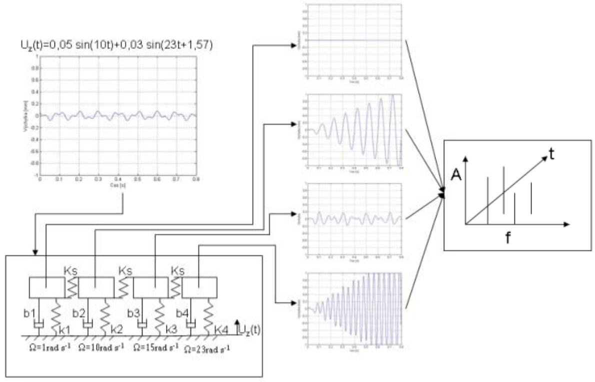

Fig. 1. Principle of signal decomposition by an array of resonators

The main goal of this work is to design the artificial cochlea which will be possible to produce by a MEMS technology. It is assumed that using of mechanical principle of signal decomposition can lead to energy saving of the device in comparison with today used full electronical cochlear implants. The energy saving artificial cochlea could be used in future as full implantable inner ear implants without using of any external device.

2. MATHEMATICAL MODEL

A basic scheme of the principle of the signal decomposition by the array of resonators is shown in the figure 1. In this case an input signal is compound from two frequency components. If the array of resonators is actuated by this signal so only those two resonators will start to resonate which eigenfrequencies are equal to the two frequency components in the input signal.

The mathematical model described in the figure 1 can be expressed by following matrix form of differential equations of motion:

$$M\,\ddot{q} + B\,\dot{q} + K\,q = \dot{q}_z\,B + q_z\,K + K_{s1}\,q + K_{s2}\,q \qquad (1)$$

In equation 1 q_z is a vector of displacement of kinematical actuation, $\dot{q}_z$ is a vector of velocity of the kinematical actuation, q is a vectors of displacement, $\dot{q}$ is a vector of velocity and $\ddot{q}$ is a vector of acceleration of the resonators. M is a matrix of mass of resonators, B is a matrix of viscous damping of resonators, K is a matrix of stiffness of resonators and Ks1 and Ks2 are matrixes of stiffness of connection springs between neighbor resonators.

Results calculated for this simple mathematical model showed that for correct signal decomposition is very important mainly value of viscous damping of the resonators and also value of stiffness of connection springs between neighbor resonators.

The results showed that it is need to use quite high value of viscous damping of the resonators for correct non-stationary

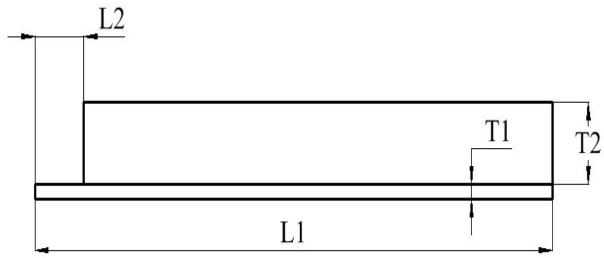

Fig. 2. Dimensions of used two layer resonant beams.

signal decomposition. Low value of the viscous damping leads to long transient effects which evoke smudging of gained spectrograms in frequency domain. The results also showed that for correct signal decomposition using of very low or zero stiffness of connection springs is need. The higher value of stiffness of connection springs lead to vibration also neighbor resonators closed to the resonator with eigenfrequency equal to the frequency components contained in input signal. This effect leads to creation of false frequency components in the spectrogram.

3. FINITE ELEMENT MODEL

On the basis of the simple mathematical model described in chapter 2 a 3D model and then also finite element model of the artificial cochlea was created. The results calculated on the simple mathematical model showed that it is need to use an array of isolated resonators without mutually connection. For this reason a two layer resonant beams are used like resonators. The two layer beams are chosen for the reason of quite high ratio between their first and second eigenfrequencies. The two layer resonat beam is schematically shown in the figure 2.

The artificial cochlea should be compound from fifty resonant beams. Every resonator is compound from 1μm thin layer which represents a spring and from 100μm layer which represent a mass of the resonator.

The artificial cochlea is designed for audible frequency range from 100Hz to 10kHz. The eigenfrequencies of the resonators are dependent after this term:

$$f_{i+1} = f_i * 1,1 \qquad (2)$$

where i = 1..49, if the first resonator has eigenfrequency f_1 = 100Hz then the last resonator has eigenfrequency f_{50} = 10672Hz. To these eigenfrequencies matches length of the first resonator 2.4mm and length of the 50^{th} resonator 0.11mm

4. RESULTS

In the figure 3 are shown amplitudes of displacement of vibration of the resonant beams in dependency of frequency of input mechanical excitation. The amplitudes of displacement were taken from free ends of the resonant beams. The calculation was made for constant damping ratio ξ=0.1 for all resonators. An amplitude of the mechanical excitation was also same for all resonators $q_z=10^{-10}$m.

5. CONCLUSION

A finite element model of the array of resonant beams was design as the artificial cochlea. The resonant beams have different length and different resonant frequency and they are compound from two layers for the reason of achievement high ratio between a first and higher eigenfrequencies of the beams. It is supposed using of fifty resonant beams in audible frequency range from 100Hz to 10kHz.

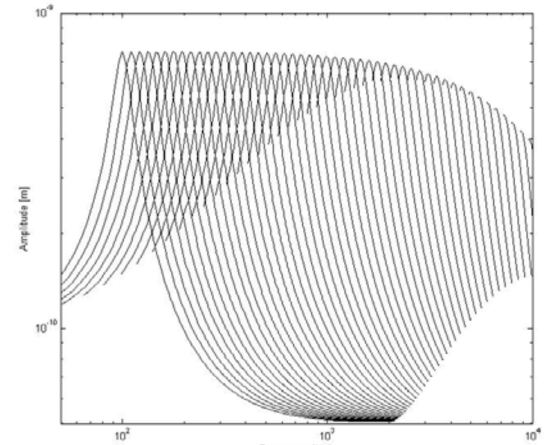

Fig. 3. Amplitudes of vibration calculated for the array of the fifty resonant beams in dependency of frequency of mechanical excitation

Next step in development of artificial cochlea will be calculation of output electrical signals in dependency of amplitude of input mechanical vibrations. For the transformation of the mechanical signals into the electrical signals is supposed to use a set of four piezoresisitors connected into a full Wheatston bridge.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Békésy, G von. (1960). *Experiments in Hearing,* McGraw-Hill, ISBN 978-0070043244, New York

Chen, F.; Cohen, I. H.; Bifano, T. G.; Castle, J.; Kapusta, CH., Mountain, D. C.; Zosuls, A. & Hubbard, A. E. (2006). A hydromechanical biometic cochlea: Experiments and models, *J. Acoust. Soc. Am.*, Vol. 119, No. 1, January 2006, pp. 394-405, ISSN 0001-4966

Gad-el-Hak, M. (2006). *The MEMS Handbook*, CRC Press, ISBN 0-8493-9138-5, Boca Raton

Rubinstein, J. T. (2004). How cochlear implants encode speech, *Current Opinion in Otolaryngology & Head and Neck Surgery*, Vol. 12, No. 5, pp. 444-448, ISSN 1068-9508

Shintaku, H.; Nakagava T.; Kitigawa, D.; Tanuyaja, H.; Kawano, S.; Ito, J. (2010) Development of piezoelectric acoustic sensor with frequency selectivity for artificial cochlea, *Sensors and Actuators A: Physical*, Vol. 158, Issue 2, March 2010, pp. 183-192, ISSN 0924-4247

Tianying, R. (2002). Longitudinal pattern of basilar membrane vibration in the sensitive cochlea, *Proceeding of the National Academy of Science of the United States of America*, Vol. 99, No. 26, pp. 17101-17106, ISSN 0027-8424

White, R. D. & Grosh, K. (2002). Design and characterization of a MEMS piezoresistive cochlear-like acoustic senzor, *Proceedings of International Mechanical Engineering Congress and Exposition*, ISBN 0791816931, New Orleans, November 17-22, 2002

*** (2010) http://en.wikipedia.org/wiki/Cochlear_implant-Wikipedia The Free Encyclopaedia, *Accessed on:2010-5-25*