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POSSIBILITIES OF USING OF MECHANICAL ANALYZER FOR DECOMPOSITION OF NON-STATIONARY SIGNALS

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Abstract: *This paper deal with possibilities of using of an array of resonators for decomposition of any non-stationary signals. A basic mathematical model composed from resonators with mutually connection and basic principle of signal decomposition is described first. Then a basic shape of simple resonant beams which can be produced by MEMS technology is described. Finally possible areas of using of the MEMS array of resonators are presented.*

Keywords: ***MEMS, signal, decomposition, cochlea.***

1. Introduction

The idea of using of a mechanical analyzer for decomposition of non-stationary signals is inspired by function of the mammalian inner ear, concretely by function of cochlea. The cochlea is perhaps the most important part of the human ear because a transmission of mechanical signals into electrical signals is done there. Very interesting behavior of the cochlea is not only the transmission of the signals from electric into mechanical but simultaneously decomposition of the whatever non-stationary signal into simple frequency components. These decomposed electrical signals are consequently transferred by hearing nerves into the brain.

The cochlea is compound basically from three fluid spaces (scala vestibuli, scala tympani and scala media). These three fluid spaces are divided by two membranes (Reissner’s membrane and basilar membrane where a hear sense cells are located) whereas the scala vestibule and scala tympani are connected by small hole which is called helicotrema. The fluid spaces together with membranes are coiled into spiral shape which looks similar like snail shell.

Decomposition of the non-stationary signals into simple frequency components is fully mechanical process. Acoustic pressure incoming from outer ear space excites ossicular chain (it is middle ear bones- maleus, incus and stapes) and through stapes is transmitted into fluid space of scala vestibuli. Consequently the pressure waves in the scala vestibule excite bending traveling waves on the basilar membrane. It is important that maximum amplitude of the traveling waves on the basilar membrane is frequency dependent. High frequencies excite the basilar membrane on its basal end and low frequencies excite the basilar membrane on its apical end. The basilar membrane has this property thanks to its special shape because the basilar membrane has different width and thickness along its length. Maximum thickness of the basilar membrane is on its basal end and minimum on its apical end whereas maximum width of the basilar membrane is on its apical end and minimum width on its basal end.

The basic cochlear mechanics was described already by Békésy (1960) He like first on the world observed the traveling waves running on the basilar membrane and for his work on mechanics of hearing was honored by the Nobel Prize in the year 1961. Today we known that big difference between mechanics of cadaver and live cochlea exist (the cadaver basilar membrane has linear mechanical properties while the live cochlea is high non-linear system with active mechanism) but the basic principle of the signal decomposition based on the mechanical resonance of the basilar membrane is valid and today generally accepted.

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Today technologies of miniaturization like Micro Electro Mechanical System (MEMS) (*Gag-El-Hak 2006*) which could be able to produce the artificial cochlea in very small dimensions are on the increase. This technology utilizes similar procedure for production of mechanical parts like procedures used in production of electronics microchips. Today a few scientists on the world try to design the MEMS artificial cochlea in the form of membrane similar to real cochlea (*Chen et al*, *2006, Shintaku et al. 2010*, *White et al. 2002*, *Tianying 2002*). Another possibility is using of an array of resonators (*Xu et al. 2004, Bachman et al. 2006*).

2. Mathematical model

A basic scheme of the principle of the signal decomposition by the array of resonators is shown in the Fig. 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.

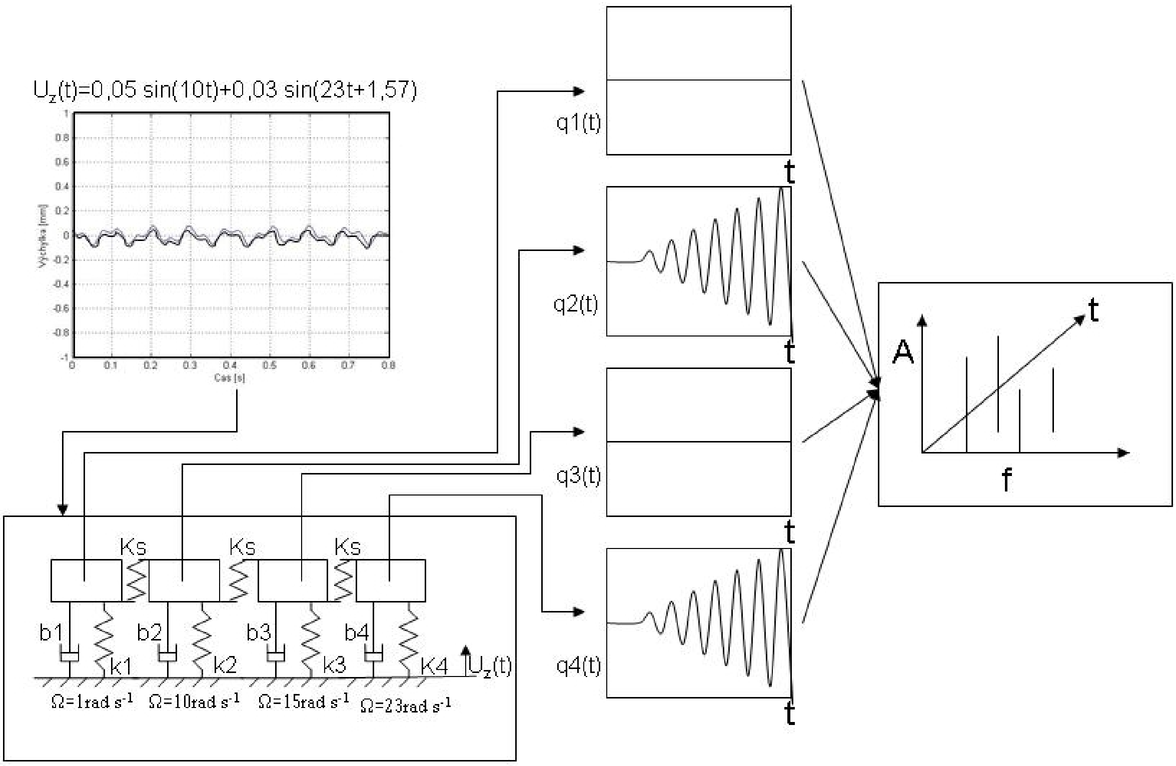

Fig. 1: Diagram of a basic principle of signal decomposition by a simple mathematical model composed from an array of mechanical resonators.

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

$$\mathbf{M}\,\mathbf{q}^{\cdot\cdot} + \mathbf{B}\,\mathbf{q}^{\cdot} + \mathbf{K}\,\mathbf{q} = \mathbf{q}_z^{\cdot}\,\mathbf{B} + \mathbf{q}_z\,\mathbf{K} + \mathbf{K}_{s1}\,\mathbf{q} + \mathbf{K}_{s2}\,\mathbf{q} \tag{1}$$

In equation 1 $\mathbf{q}_z$ is a vector of displacement of kinematical actuation, $\mathbf{q}_z^{\cdot}$ is a vector of velocity of the kinematical actuation, $\mathbf{q}$ is a vectors of displacement, $\mathbf{q}^{\cdot}$ is a vector of velocity and $\mathbf{q}^{\cdot}$ 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 $\mathbf{K}_{s1}$ and $\mathbf{K}_{s2}$ are matrixes of stiffness of connection springs between neighbour resonators.

Calculations for different value of viscous damping of the resonators and different values of the stiffness of connection springs were done. It means the matrix **M** and **K** which define eigenfrequencies of the resonators were constant for all calculations but matrixes **B** and $\mathbf{K}_{s1}$ and $\mathbf{K}_{s2}$ were different for the calculations. The results of these calculations are in more detail described in the author’s paper *Mathematical Model of an Artificial Cochlea Based on an Array of Resonators* (Dušek, 2009).

Results gained from 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 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 leads to vibration of neighbor resonators and this effect leads to creation of false frequency components in the spectrogram (Dušek, 2009).

On the grounds of the results gained from simple mathematical model a shape of resonators was chosen. For a reason of easy production by any of MEMS technologies a two layer beam was chosen without any mutually connection between neighbor beams (It corresponds to array of resonators with zero stiffness of connection springs calculated by simple mathematical model.). The value of the viscous damping of the resonant beams depends mainly on fluid medium where the beams will located. As the fluid medium is supposed to use a silicone oil. The silicone oil is produced in very wide range of kinematic viscosity (from 0.65 cSt. to 20 000 000cSt. - Clearco Products, 2011) and the silicone oil is also used by other scientist in his artificial cochlea (Shintaku et al., 2010, White et al., 2002).

The two layer beam is schematically shown in the Fig. 2. The layer T1 represents a spring of the resonator and layer T2 represents a mass o the resonator. It is supposed to use an array composed from these resonant beams which all have same thickness of layer T1 and T2. The different eigenfrequencies of the resonators should be effected through different length of the resonant beams.

Fig. 2: Shape of resonant beams.

3. Possible applications

3.1. Artificial full implantable cochlea

The most useful application of the MEMS array of resonators should be the artificial full implantable cochlea which could replace injured and functionless human cochlea. Today used cochlear implant is fully electronic device which is composed from two parts- internal (this part is permanently implanted in human head) with electrodes and external (this part is placed out of the human head) with microphone and speech processor. Both parts communicated thru skin by an electromagnetic induction coil (Rubinstein 2004, Wikipedia 2011). Although development of the cochlear implants is very significant there are not full implantable cochlear implants today. The full electronic cochlear implants are still too high consumption of energy and they have quite large dimensions. It is supposed that the MEMS artificial cochlea should be much more effective with the energy source and together with any energy harvesting systems (energy gained from warm of human body or from heart or human moving vibration) it should be full implantable. For example artificial MEMS cochlea developed by Shintaku et al., 2010 do not need any external sources because they use a piezoelectric effect for generating of the electric pulses.

3.2. Technical vibro diagnostics

Another possibility of using of the array of resonators is area of the technical vibro-diagnostics. The technical vibro-diagnostics is based in absolute majority cases in analyzing of the FFT spectrums. Classical measurement chain is composed from mechanical sensor, amplifier, anti-aliasing filter and any powerful processor for calculation of the FFT. The advantage of the MEMS array of resonator is reduction of the measurement chain only into the mechanical sensor, because filtering of the signal would be made mechanically. Another advantage is also decomposition of the signal by the array of resonators in real time and this can be used for on-line monitoring and controlling of the machines (there is not a problem to integrated the mechanical parts together with electrical controlling part on one chip).

4. Conclusions

This paper deals with possibilities of using of the MEMS array of mechanical resonator for decomposition of the non-stationary signals. Basic mathematical model of the array of resonator shown that it is need to use quite high value of viscous damping of the resonators and to use preferably separated resonators without mutually connection. With a view to easy production by any of MEMS technology a two layer beam was chosen like optimal shape of the resonators. Areas of using of the MEMS mechanical analyzer should be mainly full implantable cochlear implants and sensors used in vibro diagnostics.

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