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Review Article

Mysterious Acoustic Emission

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Abstract

There is a physical phenomenon that has accompanied humanity for thousands of years. Already in the Stone Age, people heard the sounds of breaking branches, sounds coming from eating dry food, shelling nuts. In the Bronze and Iron Ages, sounds related to metalworking were added. For several thousand years, the phenomenon had no name, the mechanisms of the emission of sound waves into the environment were not known. Scientific work began only 100 years ago. The name of acoustic emissions was created, the mechanism of the phenomenon and the methods of its study were explained. The mechanism of the formation of spontaneous acoustic emission in the ear has not been satisfactorily explained. Thousands of works and very numerous hypotheses have been created, which in itself proves that none of them is final and each has certain flaws. The final part presents some reservations about the current theory of the formation of spontaneous acoustic emission in the ear.

Keywords: Hearing; Frequency; Membrane

Introduction

There is a physical phenomenon that has accompanied humanity for thousands of years. Already in the Stone Age, people heard the sounds of breaking branches, sounds coming from eating dry food, shelling nuts. In the Bronze and Iron Ages, sounds related to metalworking were added. For several thousand years, the phenomenon had no name, the mechanisms of the emission of sound waves into the environment were not known. Scientific work began only 100 years ago. The name of acoustic emissions was created, the mechanism of the phenomenon and the methods of its study were explained. The mechanism of the formation of spontaneous acoustic emission in the ear has not been satisfactorily explained. Thousands of works and very numerous hypotheses have been created, which in itself proves that none of them is final and each has certain flaws. The final part presents some reservations about the current theory of the formation of spontaneous acoustic emission in the ear.

Acoustic emission:

Acoustic emission is a common phenomenon in nature. It has accompanied people for over 5,000 years. In the Bronze and Iron Ages, metal tools were made, and during forging, bending and hardening, sounds were generated, now known as acoustic emission. The acoustic signal was received as a warning that the metal could not be bent any further because it would break. Breaking twigs or trees produces a sound that is mechanical waves of acoustic emission. Eating dry food is accompanied by the sound of sound wave emission. Walking in the park on dry leaves generates acoustic emission waves. Mechanical acoustic waves of various frequencies from several hertz to several dozen megahertz are propagated by steel structures, wooden and masonry buildings, bridges, pipelines, large fuel tanks, electrical cables, coal and metal ore deposits, rock mass movements signaling earthquakes, grain stores, dry provisions, fruit, etc. Acoustic emissions are used to examine damage to these elements, furniture, paintings, glass, bones – e.g. knee joints, in the ear.

Such a common phenomenon has many causes for the emission of acoustic wave energy to the outside. The most common causes are material defects, microcracks, cracks, rust, leaks, active material discontinuities, phase transitions, gas sorption, fluid flows, cavitations, plastic deformations, electron jumping to lower orbits. On a microscopic scale, it is possible for atoms to jump to an adjacent position in a molecule, which is associated with the emission of an acoustic energy pulse of different frequency. There are certainly other causes, because apart from electronic and atomic changes, no cause is responsible for spontaneous emission in the ear [1,2].

The first studies on the phenomenon of elastic wave emission by various bodies were performed in the USA and Great Britain in the 1940s. At that time, frequencies were studied only in the acoustic frequency range of 16 Hz to 20 kHz. Hence the name acoustic emissions. As the measuring equipment was improved, higher and higher acoustic emission frequencies were detected. Currently, the limit reaches several dozen megahertz. In solid bodies, stresses are studied, causing deformations, small cracks, which are accompanied by a sudden emission of energy in the form of acoustic waves.

The dislocation of atoms in a molecule changes the local structure, the molecules assume a lower energy level and the excess energy is transferred to the environment in the form of mechanical energy quanta as an acoustic wave. The generated energy created at the point of generation propagates outwards in all directions in the form of elastic waves detected on the surface as acoustic emission [3]. Depending on the material and the mechanism of generation and force of action, elastic waves of different intensity and different frequency are created.

Thomas Gold can be considered to have predicted the existence of acoustic emission in the ear as early as 1930 [4]. He proposed the "regeneration hypothesis" in which electromechanical feedback counteracts viscous damping in the cochlea. Gold believed that if the self-regulation mechanism failed, excessive feedback would cause spontaneous oscillations of the hair cells. The vibrations would be transmitted back to the stirrup and into the external auditory canal. He also believed that the frequency of oscillations was closely related to the hair cells. He believed that the viscosity of the liquid was reduced by the electrical energy of the cochlear microphonic potential, which is a by-product. This potential could be a link in the chain of events that constitutes the amplification of the signal.

Acoustic emission according to Kemp [5] "is a natural consequence of the amplification of the scattered wave in the presence of internal non-pathological impedance disturbances" (?). Kemp believed that the process of multiple internal reflection of wave energy in the cochlea of the ear creates spontaneous acoustic emission. However, to study spontaneous emission, he used a pure-tone stimulus to initiate the phenomenon, drawing the conclusion that everything that starts a traveling wave on the basilar membrane causes amplification of the wave in both directions, phase shifts, and wave reflections at the border of the middle and inner ear - which leads to acoustic emission in the ear. According to Kemp, this was confirmed by the "global model" of the standing wave in the ear. He believed that in the absence of external stimulation, the activity of the cochlear amplifier increases, which leads to the production of acoustic emission in the ear. Spontaneous oscillations in the ear are the cause of acoustic emission. Oscillations are created as a result of strong cochlear resonances in the feedback process. It is believed that tinnitus is caused by acoustic emission and mechanical resonance. Such noise is called mechanical noise. Two hypotheses were created, according to one, the element propagating the emission of waves is one hair cell falling into oscillations. The second hypothesis opted for the view that oscillations appear collectively and cover the entire cochlea.

Local oscillator theorists believe that the cochlea produces sound because the hair cell becomes unstable and begins to oscillate spontaneously. Some suggest that the hairs of the hair cells are unstable and cause oscillations in the ear. Global action theorists suggest that the hair cells in the organ of Corti oscillate spontaneously in groups, and the evidence is the emission of acoustic waves.

In later years, work on explaining the causes and mechanisms of acoustic emission in the ear was carried out by: Zwicker 1986, Talmagde 1991, Sito and Meloti 1991, Shera 2003, Vilfon and Duke 2008, Duifhuis 2011, Wit and van Dijk 2012.

Gruters et al. 2018, consider that, "temporary generation of otoacoustic emissions in the ear in the case of middle ear stiffness may result from pressure changes in the middle ear cavity, due to breathing or swallowing. Spontaneous contractions of the ear muscles or eye movements may have an influence. The influence is due to changes in intracochlear pressure, dependent on blood flows." It is believed that information traveling as pressure waves back and forth along the spiral of the cochlea probably influences the generation of acoustic emissions.

Discussion:

The mechanical energy of elastic waves in the form of ultrasonic or audible waves generated inside a given object (including the ear) passes through the environment – through tissues – to the surface available for testing. An acoustic wave does not transfer mass, a pressure wave travels through subsequent environments [6]. Vibrations are tested on the surface of the tested object using a piezoelectric transducer. Acoustic emission in nature is universal and the tests should be the same, regardless of the mechanism of the phenomenon. The ear is an exception in Nature, where waves are propagated only in one direction to the external auditory canal. The emission of waves on the surface of the skull, where the waves reach, is not tested.

If acoustic emission in the ear is associated with contractions of the outer hair cells, which are considered to play the role of an amplifier of hearing, then the contraction of the cells occurs after the depolarization of the cell. [7] A receptor potential is created earlier and after the transmitter is released, an excitatory postsynaptic potential and an action potential of the auditory nerve are created. If the contraction of the hair cell is the source of acoustic emission, then auditory potential studies can be performed during the duration of the signal emission. The latency time of the potential compared to the time of emission of the acoustic wave is important.

Kemp believes that the activity of the cochlear amplifier increases when no external energy is applied. There is no explanation of the principle of depolarization of the hair cell? Without depolarization there is no contraction, no amplification, no acoustic emission. Kemp suggests the existence of back waves, the formation of a standing wave and resonance (he did not provide a forcing and forced wave) and the existence of mechanical feedback. It consists in the fact that sound waves are reflected, stimulate the stirrup plate to vibrate and the energy of the wave is conducted to the external auditory canal. A difficult concept to accept.

If no external force acts on the ear in the case of spontaneous emission, then there is no reflected wave, no backward wave. If external energy acts, then there is no spontaneous emission. The wave travels to the cupula and then to the round window. This is a degraded wave; it decays hundreds of times. This wave does not travel to the receptor, it does not travel as a backward wave to the oval window. There is no reflection from the flaccid round window of the decaying sound wave. At this time, a traveling wave travels on the basilar membrane, which does not conduct information to the receptor. The resonance of the longitudinal wave with the transverse wave of the basilar membrane is not able to provide accurate information transfer. The lack of mobility of the basilar membrane does not prevent information from being transferred to the receptor bypassing the basilar membrane and the fluids of the cochlea, as in cochlear implant surgery in the treatment of partial deafness. The signal path to the receptor leads through the bony casing of the cochlea. This is also evidenced by the signal latency time in the ECoG study.

There is no explanation as to whether the contraction of the outer hair cell itself is the source of the acoustic emission or whether the source of the mechanical wave emission is the vibrations of the basilar membrane pulled by the contracting outer hair cells.

If the cells themselves emit a backward acoustic wave, a conflict of interest arises – the backward wave of the same frequency is subject to destructive interference.

If the basilar membrane is to vibrate, the hair cell has no connection to the basilar membrane, which is located in the fluids of the cochlea with a high damping capacity. Does every contraction of the hair cell generate a back wave? Does every contraction of the outer cell, pulling on the basilar membrane, amplify the inner hair cell? The basilar membrane is burdened by the mass of the organ of Corti and the connective tissue on its lower surface and cannot vibrate independently up to 100 kHz in other mammals.

The basilar membrane has no innervation and no mechanism for regulating its tension depending on the amplitude and frequency of the wave [8].

An acoustic wave reaching any point becomes a source of a new wave. Therefore, it is difficult to understand that the backward wave on the basilar membrane acts exclusively on the stapes plate, without having any connection with it. On the way from the oval window to the external auditory canal, there is no amplification of the signal. There is attenuation of the signal. The amplitude of the wave decreases with increasing distance from the sound source.

It is possible to stimulate hair cell contractions by applying sound wave energy via the bone pathway. The evoked emission should be detected on the surface of the skull bone or on a metal plate clamped in the teeth.

It is difficult to understand why there is no acoustic emission caused by the absence of an eardrum. The acoustic emission of bones, knees, fruits, rice in a sack is studied and there is no eardrum there. This indicates the need for further search for the cause of the formation and the mechanism of energy transfer of acoustic waves generated during changes in the structure of matter at the level of nanostructures and nano mechanisms. The electronic level comes into play - electrons jumping from orbit to orbit combined with the emission of excess quantized energy. In spontaneous emission, there is a spontaneous transition of atoms or molecules of the body to a state of a lower energy level. This can be a transition to a lower orbital state, or a transition to a lower rotational or vibrational state. The number of transitions of atoms or molecules from an excited state to a native state with a lower energy level depends on the cause and on the number of atoms in the molecules in the excited state. Excited states can be electronic, rotational, vibrational and rotational-vibrational. In ground states, electrons in atoms are in their lowest-energy orbits.

There remains a question about the formation of spontaneous acoustic emission in the ear.

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