DOI: 10.61782/fa.2023.0159

forum acusticum 2023

# UKRAINIAN ACOUSTICS AT THE TURN OF THE MILLENNIUM

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## ABSTRACT

The first acoustic research in Ukraine began in the middle of the 20th century with the creation of the Department of Acoustics and Sound Engineering at the Kyiv Polytechnic Institute and the Kyiv Research Institute of Hydrodevices. The first works were dedicated to the development of electroacoustic equipment, the study of acoustic features of the premises and the design of hydroacoustic buoys and stations. In the first years of the independent Ukraine, acoustic research was aimed at creating the projects of new state premises of complex shapes (lecture theatres, conference halls, etc.). In 1991, the Department of Acoustics introduced the speciality "Medical acoustic devices and equipment". In recent years, the significant results have been achieved in the development of acoustic design and computing methods and in the construction of early passive ultrasound diagnostic devices as acoustothermometer used for measuring the internal temperature of the human body, and an auditory echoscope, which implemented a new method for diagnosing human hearing. In addition, after 2014 the department created and tested a technique for acoustic music therapy for the rehabilitation of individuals affected by the stressful situations. Much attention has been paid to the issues of acoustic signals processing and separating them from noise.

**Keywords:** *Medical Acoustics, Acoustic Signal Processing Technology, Architectural Acoustics, Hydroacoustics, Broadband Acoustic Ear Echo Spectrometer, Acoustic Thermometer*.

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## 1. INTRODUCTION

The first acoustic research in Ukraine began in the middle of the 20th century in 1936 with the opening of the Department of Acoustics and Sound Engineering at the Kyiv Polytechnic Institute. Initially, the work was related to the development of electroacoustic equipment, as well as research into the acoustic characteristics of rooms of complex shape.

The establishment in 1956 of the Kyiv Research Institute of Hydro Devices has given rise to the joint personnel training programmes (as a branch of the department was opened at the Institute of Hydro Devices) and R&D in the field of hydroacoustics.

## 2. HYDRCOACOUSTICS

Central to the entire field of hydroacoustics, the development of ship systems, aviation target search and track systems using radio hydroacoustic buoys, helicopter and positional hydroacoustic stations was launched. These developments met the international standards and were exported to 26 countries.

A considerable contribution of the Ukrainian acoustic school to the theory and practice of solving the problems of radiation and reception of sound waves, in cases when the voltage on the radiating elements is matched by the sound pressure at an arbitrary point of the medium surrounding the emitter should be noted. This takes into account the interaction of electric, mechanical and acoustic fields of hydroacoustic systems when converting and emitting the energy of emitters into the environment.

In the 20th century, advanced models of naval weapons were created in Ukraine. In the field of ship hydroacoustics, these were hydroacoustic complexes for small, medium and large ships. Moreover, the detection range of underwater objects was approximately hundreds of kilometers.

Such results were obtained due to the theoretical justification and experimental verification of the implementation of digital sonar systems of signal classification using expert systems technology, as a type of artificial intelligence system.
As part of the aviation search and sighting systems, hydroacoustic complexes were created, which were equipped with hydroacoustic buoys based on vector transducers that met NATO standards.

## 3. ARCHITECTURAL ACOUSTICS

In the first years of Ukrainian independence, due to the need to develop its own state structures and legislative framework, acoustic research was aimed at creating architectural and construction projects of rooms with complex geometric shapes (lecture theatres, conference rooms, etc.) and state building standards in the field of room acoustics and the surrounding environment.
Starting in 2005, researchers of the Department of Acoustics and Acoustoelectronics (the department changed its name in 1982), together with the Research Institute of Building Structures and other architectural and construction organizations of Ukraine, developed a number of regulatory documents on the measurement and evaluation of sound-insulating and sound-absorbing properties of materials, as well as requirements for construction and sound insulation of engineering structures, methodology for calculating sound levels in the environment and buildings. The documents fully meet the requirements of international and European standards.
In recent years, a lot of attention has been paid to the use of noise protection screens. Comprehensive studies of the effectiveness of noise protection screens were conducted using theoretical methods (method of partial areas), computer modeling methods, and experimental studies in the laboratory and natural conditions. A number of problems that did not attract attention before were identified, in particular, the assessment of the effectiveness of noise protection screens located on bridges and viaducts. Based on the results of the research, the department developed software that allowed significantly improve the accuracy of predicting noise levels and the effectiveness of screens with finite sound insulation.

## 4. MEDICAL ACOUSTICS

In 1991, the specialty "Medical acoustic devices and instruments" was launched at the Department of Acoustics and Acoustoelectronics, which opened a new page in the history of the development of acoustics in Ukraine
The department's research focused mostly on creating a methodological basis (calculation formulas), its experimental verification, design and creation of experimental samples of new electro-acoustic devices for medicine, namely an acoustothermometer of the internal temperature of the human body; broadband piezo transducers for ultrasound scanners, broadband piezo emitters for ultrasound therapy devices; ear echoscopes. The relevance of the research areas was supported by the evidence that even though the earlier attempts to create such devices were made by other researchers, they made fundamental mistakes in understanding both the principle of operation and key requirements for the devices, which did not lead to success.
Common to the theory was its construction based on electromechanical analogies, bandwidth optimization based on the method of connected circuits, which made it possible to perform calculations based on simple ratios that are uniform for different types of converters. On its basis, the following projects were calculated and put into practice: a single-channel, single-frequency acoustothermometer of the human body, which allows measuring the internal temperature of organs and biological tissues, in real time with an accuracy of 0.2 °C; a therapeutic emitter with a band of 1-3 MHz; ear echoscope – a new objective diagnostic device for measuring the quantitative parameters of the human middle ear in norm.
The absence of an acoustothermometer as a device for passive diagnostics with the accuracy of determining the depth temperature became an incentive for the department's research and the following results. For instance, the department developed the theory of an acoustothermometer of the human body's internal temperature based on thermal acoustic radiation through the skin with an accuracy of no worse than 0.2 °C in real-time using a piezo plate as a receiver of thermal acoustic radiation of the human body. The previously unknown effect of the spatial filtering of diffuse radiation by matching layers has been discovered. As a result, the intensity of the piezo transducer's electric noise significantly exceeds the intensity of the electric noise of the acoustic signal, and, therefore, the accuracy of the temperature measurement is many times greater than the threshold. It was shown that this effect in the case of the focused acoustothermometer, developed at the department of acoustics, using a plano-concave elliptical lens, allows obtaining an accuracy of 0.2 °C at a greater depth and in real-time.
Based on the obtained ratios, the scheme of the acoustothermometer was chosen – a focused

acoustothermometer, in combination with electronic switching of the piezo receiver and a noise standard, which allowed not only to dispense with single-spectral and single-beam sounding, but also to measure the temperature in real time. The Department of Acoustics was pioneering the development of an acoustothermometer, which was calculated and implemented based on the plate piezo receiver, an elliptical lens and blocks of two serial voltmeters.

In addition, over time ultrasound therapeutic emitters gained popularity in medicine. It should be noted that the radiation mode can be either continuous or pulsed. The operating frequency range from 1 MHz to 3 MHz was initially overlapped using a set of single-frequency emitters, the essential disadvantage of which is the need to move them during the procedure. This is caused by the need to avoid local damage due to the possible formation of standing waves and "hot spots".

For the first time, it was the Department of Acoustics that developed a broadband electro-acoustic system consisting of a plate piezo radiator, with one matching layer, and two electrical correcting links, which had a bandwidth of 1-3 MHz and did not need to be moved. An equivalent circuit of a piezo element in the form of a complex oscillating circuit was also used to obtain calculated ratios for the optimal parameters of broadband piezo emitters.

Another area of research focuses on the human hearing device. It was mainly studied to properly formulate the requirements for electroacoustic equipment and equipment for the restoration of hearing impairment. The disadvantage of the existing methods of objective diagnosis of the hearing was that it was necessary to subtract the impedance of the closed section of the external auditory canal between the ear insert and the eardrum from the value of the acoustic impedance of the middle ear. The new method of ear echoscopy proposed by the researchers did not have this drawback. It allows measuring the sound reflection coefficient for one short pulse, that is, to observe the process in dynamics during one sample, which makes it possible to highlight individual features of the ear's oscillatory system. This task is especially important in the case of operative restoration of hearing by replacing the auditory ossicles and for screening the hearing of newborns directly in maternity hospitals. In addition, the ear echoscope eliminates the need to use a pneumatic system, as is the case in acoustic impedance measurement, which is dangerous for newborns.

According to the existing research, the reflection coefficient, and therefore, the magnitude of the echo signal should be small. It was necessary to create a mathematical model of the ear. Using the method of equivalent circuits, it was shown that the equivalent circuit of the middle ear was two connected circuits.

Based on the equivalent scheme, the formula for the parameter of the middle ear in norm was obtained theoretically and confirmed experimentally by deciphering tympanograms. From a physical point of view, it is a condition for optimizing the parameters of the auditory system to the maximum bandwidth in the speech range – the equality of the unit, the so-called communication factor. From a medical point of view, it is a normal parameter. This made it possible to carry out objective differential audiometry, that is, to determine the loss of auditory sensitivity not only without the participation of the subject, but also separately in the sound-conducting and sensorineural systems.

Having analysed the experimental data regarding the value of the active component of the acoustic impedance of the middle ear in the norm, the principle of sound reflection from the tympanic membrane was formulated: the minimum value of the energy reflection coefficient of the sound from the tympanic membrane and the maximum value of the energy transmission coefficient are close to 0.5. This completely disproved the existing notion that "when the elements of the middle ear are in normal condition, the eardrum absorbs sound energy well and only a small part of it is reflected into the auditory canal, as a result of which the eardrum effectively transmits mechanical vibrations to the ossicles of the middle ear."

## 5. ACOUSTIC SIGNAL PROCESSING TECHNOLOGY

For all the years of the existence of the acoustic school in Ukraine, a lot of attention was paid to the problems of processing acoustic signals and separating them from noise. First of all, this referred to language processing. The effectiveness of speech communication systems and automatic speech recognition depended not only on the type of speech (commands, processing), but also on the acoustic environment (noise, reverberation) and the characteristics of communication channels (filters, codecs). Therefore, in recent decades, special attention of Ukrainian researchers has been attracted by speech modelling methods in conditions of increased level of ambient noise and signal distortion inherent in communication lines.

One of these methods is the creation of speech corpus-databases in the form of sound and related text files. The greatest results were achieved by specialists of the Institute of Cybernetics of the National Academy of Sciences of

Ukraine and the Ukrainian Association for Information Processing and Pattern Recognition.

In addition, it should be noted the achievements of the scientists of the Department of Acoustics and Acoustoelectronics include the research into complexes of computer programs for modelling and measuring speech intelligibility, formant-modulation method for evaluating speech intelligibility, measurements accuracy of the distribution function of the speech levels of signals.

One of the recent vivid examples in this direction is the participation of the department's scientists in the staging of live acoustic experiments and technical examination of the materials related to the substantiation of the innocence of the Ukrainian citizen Vitalii Markiv, who was accused of the death of an Italian journalist in June 2017 near the Slavyansk city. In November 2020, the Italian court agreed with the conclusions of the scientific and technical materials provided by the Ukrainian side, acquitted Mr. Markiv and returned him to the Motherland.

## 6. CONCLUSIONS

In 2020, there has been an important reorganization – two departments were invited to join their effort to reinforce the research. The Department of Acoustic and Multimedia Electronic Systems was created as a result of merging the Department of Acoustics and Acoustic Electronics and the Department of Sound Engineering and Information Registration into one unit. The successful and rich history of acoustics in Ukraine has been continuing in the 21st century!

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