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Fifty Years of Polish Hydroacoustics

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INTRODUCTION

Hydroacoustics as part of acoustics is one of these branches of science which consolidate people who represent different, and at the first glance distant, specializations. Its features are adequate for interdisciplinary sciences. Solving hydroacoustic problems can occupy the following specialists: a physicist, an electronic engineer, an oceanographer, a biologist, a mathematician, a computer scientist and a mechanical engineer. The experience of scientists dealing with biomedical applications of the ultrasonic techniques or of those who investigate the atmosphere with sound is also appreciated.

Hydroacoustics demands solving many theoretical problems of the basic character. The research requires finding the mathematical description of a few physical phenomena such as sound propagation in the medium of random varying features, radiation by sources of various aperture or sound scattering. On the other hand, practical applications demand creating devices of extremely high precision and technical complexity.

The sea environment can be investigated by means of the acoustical methods in many ways. There are a few objects of measurements such as underwater ambient noise, the distribution of sound field generated by different sources (also by a moving ship), sound scattering or acoustic parameters of the medium. Fish resources or the geological structure of the sea

bed may be estimated by means of acoustical methods, too. The wide range of carried out experiments results in the development of signal processing methods.

After the enormous losses in the Second World War the Polish economy as well as the science restarted their activity. Hydroacoustics started to develop almost from scratch. First hydroacoustic devices were assembled of the equipment collected from the sunk ships and vessels.

A figure whose professional activity ties in well with the history of Polish hydroacoustics from the pre-war period is been Commander Wieńczysław Kon. He was an officer of the Polish pre-war Navy and was awarded a Cross of Military Merit and Courage for bravery in the battle of Narvik. After the war he devoted his entire professional life to practical applications of sonar systems and navigation equipment. He was also a dedicated teacher of both navy and merchant navy officers in the above subject. He was a lecturer in the following colleges: Navy Officers' School, Technical University of Gdansk, State Sea Fisheries School and Merchant Marine Academy. His publications include a handbook "Navigation equipment" (1967) that he was a co-author of. He was the author of the part which concerned hydroacoustic devices. He also wrote numerous publications, mainly in the marine journals.

In the fifties first scientific research on hydroacoustics was initiated by young scientists who came to the Gdańsk coast,

in particular by Zenon Jagodziński and Józef Góra, who defended first doctoral theses in this area, under the supervision of professor Ignacy Malecki.

First research groups working on development of hydroacoustic systems were created in the early sixties. Two research centers started their activity - one at the Technical University of Gdańsk, the other at the Navy.

At the end of the sixties a research ship for the Polish fishery r/v "Professor Siedlecki" was built under a FAO/UNDP project. The project which consolidated the scientists from the Sea Fisheries Institute in Gdynia and the Technical University of Gdańsk resulted in foundation and further development of the fisheries hydroacoustics in Poland.

Another research group started their activity in the beginning of the eighties, at the Institute of Oceanology of the Polish Academy of Sciences in Sopot.

Apart from the research centers listed above, there also exists the Research & Development Marine Technology Center (CTM) which designs and produces sonar systems in cooperation with the Technical University of Gdańsk. The radio manufacturing factory (RADMOR) also produces hydroacoustic devices, viz.: echo sounders, sonars and doppler logs.

SCIENTIFIC ACTIVITY OF THE MAJOR UNDERWATER ACOUSTICS GROUPS

TECHNICAL UNIVERSITY OF GDAŃSK

The work in the area of hydroacoustics in Poland was undertaken in the early fifties at the then Department of Radio Navigation headed by professor Jagodziński. He began his career in the late forties at the Marine Radio Service (MORS), after he had returned from Great Britain, following his graduation at the Polish University College. Professor Jagodziński designed the first Polish echo sounder, which for many years was continually manufactured. He had remained loyal to his technical and scientific interests in hydroacoustics through all his professional life. Supervised by him, first hydroacoustic communications equipment was built at the Department of Radio Navigation. Those devices were designed for divers and submarines (L. Skinder, Z. Czarnecki, E. Brudło, Dr S. Kubica).

The early technical operations of the Department of Radio Navigation (which featured the development of such equipment as an FM sonar, a passive sonar and a system of underwater navigation) with time were converted into extensive scientific, educational and technical activity in the area of hydroacoustics. To reflect that, at the end of the sixties, the department's name was changed into the Department of Hydroacoustics. It was headed for almost 20 years by Prof. Jagodziński. First graduates of hydroacoustics were awarded diplomas in 1968 and over the next 30 years the number of graduates exceeded 150.

At the turn of the sixties and seventies the UNDP/FAO project gave rise to a new area of interest at the Department of Hydroacoustics, i.e. fisheries hydroacoustics. Professor A. Stepnowski, Professor R. Salamon, Dr J. Burczyński and W. Martin developed at that time a computer system of estimating fish resources. The system was installed at R/V "Professor Siedlecki". It was the first Polish system of signal processing in real time. For this system and for the "method of thin layers" used in the system for the purpose of estimating fish resources, they were awarded the Minister's Award and the titles of Champions of Polish Technology. Further scientific work on fisheries hydroacoustics has been continued and is headed by professor Stepnowski. The major results of the work are computer systems of fish resources estimation ECOLOG using a dual beam target strength estimation. These systems were developed in Canada for the Bedford Institute of Oceanography. The achievements in this area have been highly appreciated in the world which has been confirmed by the employment the faculty have had with FAO and in the USA (MIT), Canada (BIO), Turkey (METU) and Indonesia (IPB). The accomplishments in this area have been published in one monograph and in articles in ULTRASONICS, Archives of Acoustics and Proceedings of Acoustical Imaging and elsewhere. The research results were presented at numerous scientific conferences, for example, at the ICA Congresses in London and Paris, International Symposium of Fisheries Acoustics (Seattle), II and III European Underwater Acoustics Conference. Acoustics surveys have been carried out by the faculty team (Prof. Stepnowski, Prof. Salamon and Dr Kilian) in the Atlantic, the Indian Ocean, the Mediterranean and the Baltic Sea.

Another important part of the Hydroacoustics Department's work were the problems of generating and propagation of acoustic waves in water. In the seventies Prof. Salamon's research initiated the new activities. He conducted the research on the method of pulse response used for ultrasound transducers and acoustic fields. In the eighties these subjects were extended by diffraction and acoustical imaging (Prof. H. Lasota and Prof. B. Piwakowski). The results of the research were published in 3 monographs, articles in JASA, Acustica, Archives of Acoustics and presented at FASE conferences, Acoustical Imaging and others.

Parallel to scientific research the Department of Hydroacoustics carried out research and development work on a large scale. Headed by Prof. R. Salamon, the first Polish multi-beam sonar, called FLAMING A was constructed. It had a phase-shift beamformer of an original construction with operating amplifiers. At the same time a team headed by Dr L. Kilian designed a side scan sonar with a system of multiple signal transmission. Both types of equipment (after some modification) are currently manufactured and used by the Navy. A series of specialist devices for research purposes was constructed as well, such as the Doppler log, a system of hydroacoustic navigation for models of ships, a sonar for ROV, an FM sonar for divers.

The last decade has brought a considerable change in the directions of scientific and technical activity of the Department of Hydroacoustics. Prof. Jagodziński, who created the Department and was a pioneer of Polish hydroacoustics has retired. He was awarded the title of Doctor Honoris Causa of the University of Surrey.

The Department changed the name into the Department of Acoustics and extended its activity into other fields of acoustics. However, the subject of hydroacoustics continues to be the main domain. Owing to the change of the political and economic system, the scientific priorities have changed as well. Hydroacoustics is recognizing more and more the environmental issues, water management, navigation and food supply. These problems have been founded by the National Committee for Scientific Research and the Department of Acoustics has been working on 6 grants related to these issues. A team headed by Prof. Salamon has developed

several devices to examine inland water areas (devices to measure the sound speed, the speed of water flow, a hydrographic echo sounder, a dual frequency echo sounder for examining bottom sediments). The team is currently working on the construction of a multi-beam sonar with a digital beamformer for the purposes of inland fisheries and on methods of estimating the spectrum of hydroacoustic signals. The team headed by Prof. Stepnowski, under National Committee for Scientific Research grants, has designed a dynamic GIS system to monitor marine living resources called ECHOBASE and a computerized system of monitoring and identifying the types of seabed VBT (Visual Bottom Typer). The team also deals with systems of sea bottom classification using artificial intelligence methods and fractals and new methods of estimating fish target strength.

Technical work is being continued for the needs of non-governmental institutions, too. An example could be the construction of two hydroacoustic control systems of ship's berthing in the Port of Gdansk (headed by Dr J. Marszal).

It needs to be stressed that the faculty of the Department of Acoustics have been co-operating for many years with Dr R.C. Chivers, D.Sc. from the University of Surrey in Great Britain. This co-operation was started by professor Jagodziński and professor Stepnowski during the ICA-74 Congress. It has been continued up till now by Profs. Salamon and Stepnowski. The main area of collaboration is methods of sea bottom typing and ultrasonic transducers. Dr Chivers also worked with Prof. Leszek Filipczyński from the Institute of Fundamental Technological Research of the Polish Academy of Sciences in the area of ultrasonic transducers. He also conferred the academic degree of Doctor Honoris Causa on Prof. Jagodziński. As a recognition of his contribution to Polish acoustics he was awarded honorary membership of the Polish Acoustic Society.

THE NAVY AND NAVAL ACADEMY

It was almost at the same time period as at the Technical University of Gdańsk that a new group was formed to deal with hydroacoustics for the needs of the Polish Navy. In the early sixties hydroacousticians centered around the Acoustics Laboratory at the Research Center of the Navy.

The earliest research was difficult to conduct mainly because of lack of equipment and measurement sensors. The main task of the laboratory was to assemble measurement tools. The first sensors used for measurements were not standard as they were made in the laboratory.

The main research conducted by the laboratory was in line with the needs of the Navy. The purchase of professional measurement equipment of Bruel & Kjaer made it possible to carry out systematic studies of underwater noise especially that made by minesweepers. The results of the studies on underwater noise were later used in the doctoral dissertation of Jerzy Regent.

The basic directions of research in the sixties encompassed:

- studies of the underwater acoustic field of ships combined with research on vibrations in order to identify the sources of noise and determine the effect they have on the field produced by a ship - an attempt to evaluate the performance of a ship;
- examining the conditions of work on a ship in the area of acoustics - noise measurements;
- in co-operation with the Military Medical Academy (WAM) (Prof. Klaiman) in the area of ergonomics and the comprehensiveness of speech under water; a device was made to examine the possibility of locating underwater sources of sound in the audible frequencies band; the device consisted of a set of underwater loudspeakers placed in a pool.

In 1973 the Laboratory of Acoustics was incorporated into the structure of the Naval Academy in Gdynia. At that time one of the basic research problems was minimization of self noises of ships and noise control on ships. To do that research on vibroisolation of ship devices and vibroisolation materials was conducted. The work had a significant practical meaning. The results were applied directly and verified in construction solutions of the ships. Dr Andrzej Muszyński and Dr Henryk Chodkiewicz dealt with the research on vibroisolation.

Within work on minimizing ships' self noise, research was conducted on the noise made by ship propellers, including acoustic phenomena during cavitation on ship propellers. Also methods to reduce ships' self noise were being elaborated. In the 70s intensive work was carried out to design and construct low noise propellers. A lot of credit should be given here to Prof. Tadeusz Koronowicz from the Institute of Fluid Flow Machinery of the Polish Academy of

Sciences. The research on the acoustic effects present during cavitation were quite significant, too. Prof. Eugeniusz Kozaczka from the Naval Academy dealt with the noise produced by ship propellers working in the sub-cavitation and cavitation range. Problems of low noise ship propellers were solved in close co-operation with shipyards. The practical effect here were technical solutions used on minesweepers of the Navy. The results of experimental studies on acoustic effects produced by a cavitating propeller were used for Eugeniusz Kozaczka's post-doctoral dissertation in 1978 published as a monograph. The problems of cavitation and acoustic effects related to cavitation continue to be the subject of joint projects carried out at the Institute of Fluid Flow Machinery and the Naval Academy.

Another issue that began to evolve in the 70s was design and construction of generators of underwater noise with a given frequency characteristics. It was mainly Dr Aleksander Kołodziejewski who dealt with the designs of mechanical generators - imitators of ships' noise. He had been granted approximately 15 patents for the solutions used in the generators and other equipment.

A more general research was also undertaken, namely studies of the sea noise and the conditions of acoustic waves propagation in shallow sea. What is worth noticing here is the work conducted by a team headed by Prof. Michał Holec. Basing on numerous results of experimental research, the characteristic seasons for the propagation of acoustic waves in the Baltic were selected. Characteristic distributions of the sound speed were determined for these seasons and also seasonal propagation models were developed. The results of the studies were used in a post doctoral dissertation. Within the work on propagation of acoustic waves in the sea, Prof. Kozaczka was carrying out extensive research on propagation in shallow sea. It included the practical, model research in a measurement pool and experimental research in the sea.

The majority of the projects used information included in underwater noise. Therefore a lot of attention was devoted to perfecting the measurement methods, and to providing for the laboratory the best professional equipment available. Latest methods of processing and analyzing signals were developed and applied.

In the 80s systematic work on piezoceramic transducers was started and on their usage in hydroacoustic measurements. The work was conducted in co-operation with the Pedagogical College of Rzeszów. The effect was that two patents were awarded in the area of construction of measurement hydrophones and also a handbook written on piezoceramic transducers. Additionally research and development work was started on the construction of underwater sensors of acoustic pressure. A prototype series of hydrophones to measure underwater noise was made. They were later used to construct a coastal noise range. Another device that was developed and made using self-designed sensors was a cavitation diagnosis tool. This device has a measurement sensor placed near the propeller. The performance of a ship propeller is assessed basing on spectral analysis of noise. What is made possible here is the detection of the beginning of a ship propeller's cavitation and observation of the acoustic effects as this phenomenon evolves.

Another important research problem that was applied in the construction of devices was the development of a concept and construction of sources of strong acoustic waves: short-circuit magnetic transducer and sparker.

Some more general research includes research on the absorption of strong acoustic waves by a two-phase medium - water-air and examining seabed using acoustic methods. The results of this research were used in the doctoral dissertation of Andrzej Muszyński.

In 1985 at the Naval Academy the Department of Hydroacoustics was established, headed by professor Eugeniusz Kozaczka. The group continued the work which had already been started, especially on the analysis of underwater noise produced by ships and the conditions of acoustic waves propagation in the sea. Seasonal changes of waves propagation in the southern Baltic were studied. Also a theoretical model of selected phenomena was developed.

Based on the results of ships' underwater noise measurements a theoretical and empirical model was designed on the distribution of the acoustic field produced by a moving ship in the proximity to its hull. A catalog of acoustic characteristics of selected types of ships was put together. Based on that a method was elaborated and used to verify the correctness of acoustic characteristics of ships using expert methods.

Since the early 90s research on ships' underwater noise has been evolving towards identification of acoustic signals emitted in water.

One of the major works carried out by the Hydroacoustics Department was the construction of a coastal noise range. It was made available for use in 1992. It has a device that registers the results of measurements and enables an instant analysis. It is used for regular measurements of ships' underwater noise and to assess the correctness of their acoustic characteristics.

Since 1985 the Hydroacoustics Department of the Naval Academy has been conducting research on nonlinear acoustics. Experimental and numerical studies have been made on the interaction of high intensity waves in water and seawater. Studies have been made on the effects of the changes of hydrological parameters of seawater on changes of its nonlinear features that are characterized by a value of the nonlinearity parameter B/A . Some interesting results in this area were obtained by Dr Grelowska. A method was developed to measure the nonlinearity parameter of water and in co-operation with the Department of Acoustics of the Technical University of Gdańsk a device was built to measure this parameter in the sea.

The achievements of the Hydroacoustics Department have been presented in numerous articles in scientific journals and at scientific conferences i.e. International Symposium on Nonlinear Acoustics in Novosibirsk and Nanjing, Forum Acusticum in Antwerp, European Conferences on Underwater Acoustics in Luxembourg and Heraklion, Conferences on Undersea Defence Technology. The results of investigations have also been used for monographs, handbooks also doctoral dissertations. 15 doctoral dissertations in hydroacoustics have been promoted in the Naval Academy.

SEA FISHERIES INSTITUTE

At the turn of the sixties a FAO/UNDP project resulted in the construction of an oceanic research ship r/v "Professor Siedlecki" which was the most modern and the largest in the world. It was the beginning of the real hydroacoustic research in this institute. The first phase demanded the installation of the unique multi functioning hydroacoustic system on the ship. The works were accompanied by a number

of scientific visits and training in the outstanding fisheries hydroacoustic centres in the world (Norway, the UK, the USA).

A group of researchers from Sea Fisheries Institute, including Dr Janusz Burczyński and Dr Andrzej Elminowicz together with faculty from the Department of Hydroacoustics of the Technical University of Gdańsk undertook the problems of detecting and estimating fish resources using the amenities of the oceanic research vessel. Dr Janusz Burczyński is the author of a well known „Manual on fisheries hydroacoustics” published by FAO in three languages.

The main topic of the hydroacoustic investigations was estimation of both the distribution and the amount of usable fish resources in the explored regions. Apart from fish there were other objects of interest such as krill (Antarctica) and oceanic plankton (cruises to the open ocean). The aim of the research triggered off the development of the methods of estimating the resources which included the computerization and calibration. Dr Janusz Kalinowski was involved in the research of krill resources.

In addition to the projects listed above the own acoustical method of seabed identification was elaborated and verified by Prof. Andrzej Orłowski.

In 1993 the Sea Fisheries Institute obtained a multipurpose research ship r/v "Baltica" which replaced the oceanic research ship r/v "Professor Siedlecki". It restricted the area of investigations to the Baltic Sea. New hydroacoustic equipment will be installed on the ship this year.

The specialists from the Sea Fisheries Institute took part in international projects co-operating with NOAA, FAO, UNESCO and ICES. As FAO experts they worked in Asia, Africa and Latin America, carrying out the investigations and training new groups of hydroacousticians.

The works in the Sea Fisheries Institute resulted in 5 doctoral theses, a handbook on fisheries acoustics, many publications in Poland and abroad, and also patents.

INSTITUTE OF OCEANOLOGY OF THE POLISH ACADEMY OF SCIENCES

The Hydroacoustics Laboratory at the Institute of Oceanology, Polish Academy of Sciences which is directed by Prof. Zygmunt

Klusek has been operating since the beginning of the eighties. The first steps in development of Hydroacoustics Laboratory were done under auspices of Prof. Śliwiński who was a supervisor of a few doctoral theses. The main topics of the research have been: the problems of sound propagation conditions in the Baltic Sea, ambient noise and scattering on heterogeneities. The scientists of the Laboratory (Dr. J. Szczucka, Dr J. Tęgowski and others) estimate the distribution and concentration of gas bubbles and plankton migration basing on the measurements of volume and bottom reverberation. The influence of gas bubbles concentration on the scattering of acoustic waves is also estimated. A method of recognizing the bottom sediments basing on the measurements of the bottom backscattering was worked out and applied afterwards to create an "acoustic map" of sediments in the Polish economic zone.

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