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THE INVENTION AND DEVELOPING OF MULTIBEAM ECHOSOUNDER TECHNOLOGY

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ABSTRACT

When a man has mastered the ability to travel by sea, he began to wonder what is the depth clearance under the keel and how to measure the depth. Initially, only coastal shipping was practiced. Cargo ship sailing, fishery, underwater scientific research, recreational diving as well as resource exploration and operation of submarine cables and pipelines laying were developing dynamically in this part of the continental shelf. That is why accurate bathymetric information was of great importance to masters, scientists, fishermen, ship-owners and all seafarers.
Cartographic compilation of even a primitive nautical chart was a huge challenge. It was a painstaking process and required, first and foremost, a large amount of data, which was primarily obtained through not efficient measurements. As technology progresses, new techniques and methods of ocean exploration have developed. The technology, systems, devices and instruments of underwater exploration have gone through a long way of change, modernization and improvements, ultimately creating the potential for a bottom surface visualization as three-dimensional spatial models. A significant role has been played by multibeam echosounder which revolutionized the hydrographic surveys and proved to be efficient means of hydrographic and oceanographic surveys.
Keywords: leadline, sounding machine, acoustic sounder, multibeam echosounder.

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INTRODUCTION

Today acoustical research methods are used in depth measurements because of their high efficiency. Among those most effective are characterized by MBES (Multi-beam Echo Sounder), capable of simultaneous depth measurement in several dozen points of the bottom surface. This advantage has certainly increased the popularity of these devices, especially in hydrographic survey. Unrestricted access and ever-lower cost of MBES production have led them to increasingly replace classic single-beam sounders.

FIRST DEPTH MEASURING INSTRUMENTS AND DEVICES

The pursuit of man to discover and explore the bottom of the ocean gave birth to a new science called Hydrography, which was born more than 3700 years ago. The methods and techniques of bathymetric measurements have evolved over the centuries from very simple and primitive to complex and fully automatic ones. The first traces of the depth measurement were found in the paintings of the Egyptian tombs. The Egyptians used to measure the depths (up to 20 meters) using poles, spades and ropes. These measurements were mainly made to provide safe navigation a short distance from the coast.

Initially, sailors were able to measure depths only in shallow waters, their interest focused on locating navigational dangers. For this purpose, they used a hand-held sounder (leadline), which was lowered from the side of the ship. Depth measurement consisted of measuring the length of the rope at the moment the weight hit the bottom. Movement of the vessel and surface currents caused unconfirmed alignment of the line in the water table, which affected the accuracy of the measurement [1].

For the next dozen or so centuries little changed. In the twelfth century AD, a magnetic compass was introduced and navigational equipment upgraded. In the 15th century after the discovery of America and Africa, the hand-held sounder remained the primary measuring device. In 1490 Leonardo da Vinci stated that sound spreads not only in the air but also under the water [2]. He also described how to hear the noise from distant ships using a tube. For another 200 years, the technique of bathymetric measurements did not change radically.

In 1773 Captain Constantine John Phipps released a rope with a load of 68 kg from the deck of H.M.S *Racehorse* in the Norwegian Sea. He measured the depth of the sea at exactly 1249 meters [3]. In 1840 Sir James Clark Ross made the first deepwater measurement in the South Atlantic recording a depth of 4434 meters. Around 1850, American naval officer Captain Matthew Fontaine Maury created the first bathymetric chart of the North Atlantic basin. Unfortunately, this chart contained numerous errors and did not reflect the actual shape of the sea bottom.

From the late nineteenth century to the early 20th century mechanical sounders were experiencing their splendour [4]. In 1872, Sir William Thomson (later Lord Kelvin) constructed a primitive mechanical sounder built of steel wire wound on a drum. The first attempts he made were on a private yacht called „Lalla Rookh". Mechanical sounders have evolved from relatively simple to complex, operated by several operators. Among the most famous are the Lucas, Sigsbee, Lietz, Tanner and Kelvin sounders (Fig.1).

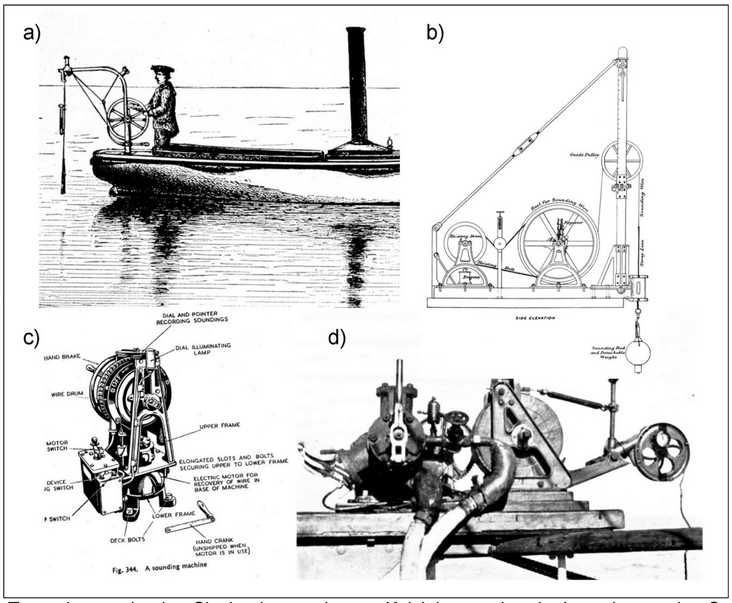

Fig. 1 Mechanical sounding devices (a - Tanner's sounder, b – Sigsbee's sounder, c – Kelvin's sounder, d – Lucas's sounder. Source: [5,6,7,8].

BEGINNINGS OF ECHO SOUNDING

Probably the first measurement under the water surface using acoustic waves was conducted in 1826. Swedish physicist Daniel Colladon and French mathematician Charles Strum measured surprisingly with high precision, the speed of sound in Lake Geneva. They obtained a value of 1435 m/s. After the outbreak of World War I, the pace of work on the construction of sonar systems increased.

The first active sonar ideas and patents appeared in 1912 after the Titanic tragedy. In that year the English meteorologist Lewis Richardson [9] patented the idea of a sonar device. A similar patent was obtained a year later by German physicist Alexander Behm [2]. The first experimental system was created in 1912. It was built by Canadian physicist Reginald Fessenden working for the American company Submarine Signal Company [10]. In 1914 sea trials were made from the deck of the *Miami* Coast Guard of the United States. Fessenden's oscillator was used to communicate with a submerged submarine, to determine the depth of the sea and to detect the iceberg.

During the First World War, sonar systems found numerous uses in warfare. As early as 1915, Russian engineer Constantin Chilowsky and French physicist Paul Langevin designed a transceiver based on piezoelectric crystal quartz. A year later they received an echo from a depth of 200 meters.

In 1917 Langevin built a quartz piezoelectric sounder working at 150 kHz. The design of the sonar proved to be impractical due to the size of the quartz and too high operating voltage. Ultimately, Langevin designed a sounder operating at 40 kHz and tests conducted in February 1918 confirmed the effectiveness of the submarines detection [9].

During this time, British scientists also worked on a secret experiment on the search and detection of submarines. English research with sonar under Robert Boyle began in 1916. His team of researchers, based partly on earlier French experiments, built the first practical sonar in mid-1917.

All of Boyle's teams' work was bound by the highest security classification. In 1919 the French made bathymetric measurements at a depth of 60 meters at a speed of 10 knots. In 1922 they investigated the location of the submarine cable from Marseille to Philippeville in Algeria. These measurements are considered by some to be the first practical hydro acoustic survey. In the years 1925 and 1927, on board the RV *Meteor*, the German expedition carried out the first large-scale bathymetric measurements using a single-beam echosounder (SBES).

At the end of the thirties of the last century, the first generation of echo sounders with magnetostrictive transducers appeared and were part of the equipment required for warships in World War II. During this period, sonar technology was rapidly developed and progress was made possible by the increasing computing power of computers and the use of digital signal processing [11].

Until World War II, the vast majority of depth measurements were made using a hand-held sounder (so-called leadline). The development of measurement techniques has made the classic hydrographic echosounders more and more popular, which has contributed to the amount of survey data, the accuracy of sea charts and the safety of navigation [12]. In the 1950s, the transducer manufacturing technology was improved and the acoustic signal time accuracy was increased. Accurate sounders and precision depth sounders and recorder (PDR) appeared with the beam width of 30º-60º [13].

These systems became fully operational with the invention and introduction of electronic beam stabilization in the 1960s.

THE INVENTION OF THE MULTI-BEAM ECHOSOUNDER

The first models of multi-beam echosounder, as a secret navy project, appeared in the 1960s [14]. General Instruments Corporation patented the depth measurement technique with not a single but several narrow beams. That's how the Sonar Array Sounding System was created (SASS) [2]. On the commercial market, this echo beam was only available in the late 1970s [15].

The oceanographer Morris Glenn presented the first information and data about multi-beam echosounder in [16]. Glenn has characterized the Multi-Beam Array Sonar Survey System. This system was operated then by the US Naval Oceanographic Office and at that time it was a revolutionary solution. The sounder has 16 acoustic beams formed in an angular sector of 90° with the ability to measure 60 depth values in one pulse. The SASS system was originally installed on an Australian *Cook* research vessel.

The need for full survey data coverage forced researchers to use new measurement techniques. Scientists were interested not only in the depths beneath the ship's hull but also some distance from it. Hence, the concept of measuring on parallel profile lines was developed, and single-beam echosounder transducers were mounted on a long boom [17].

This method was mainly used in the study of the bottom of the lake and in the open sea; but with a slight undulation it was completely impractical. A similar method of depth measurement using towed echosounders is described in [18]. A more advanced parallel sounding method is presented in [19].

In the 1960s, the Swedish Hydrographic Department developed a new hydrographic method. Instead of one unit, an array of several vessels measuring depths along parallel survey lines was formed. The array consisted of a mother-unit whose position was determined by the shore stations and accompanying boats positioned from the mother ship.

The first multi-beam echosounder (MBES) designed for measurements on shallow waters has been characterized in [20].

The system, called *Bo'sun* Multi-Beam Sonar System, was created in response to the increased number of super-tankers travelling through shallow channels, straits and port waters. The measuring system was a transducer, catamaran, console, data recorder, digital compass, magnetic tape, pitch and roll sensors. The sounder created 21 acoustic beams in the 105º angular sector, providing coverage of 2.6 times the water depth. The operating frequency was 36 kHz and the maximum depth that could be measured was 800 m. Pitch and roll sensors and transducers were installed on the catamaran (figure 2). One of the failures of the echosounder was the lack of sufficient computing power. Measurement data was recorded on magnetic tapes in a format compatible with computer stations. Experiments gathered in the first sea trials with the use of the Bo'sun echo sounder was presented by McCaffrey in [21].

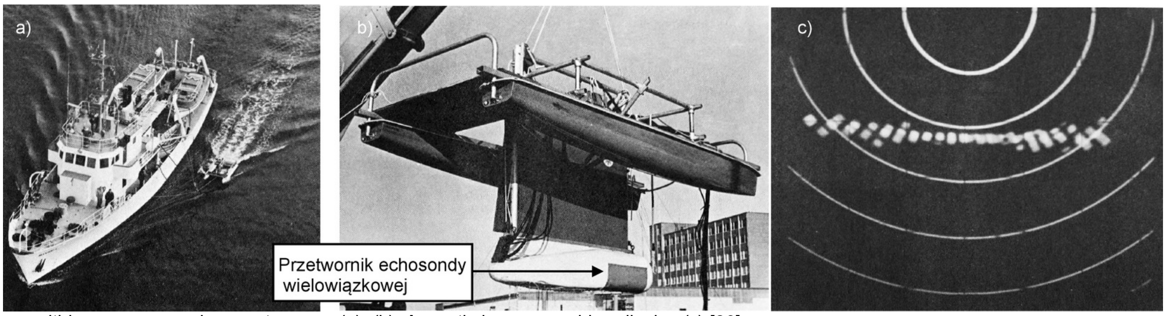

Fig. 2 Bo'sun multi-beam survey using a catamaran (a), (b). Acoustic beams on video-display (c) [20].

In the early 1970s, deep-water multi-beam echosounders appeared in the public sector. The first such system constructed by General Instrument Corporation (GIC) was the *Sea Beam* echosounder, which was tested in 1977 aboard the ship *Jean Charcot* (fig. 3). The technical description of the echosounder is shown in [22]. The echosounder generated 16 beams forming an angle of about 90° [8]. The acoustic signal frequency was 12 kHz.

During this time intensive work was done on electronic beam steering, bottom detection algorithms and the acoustic ray trajectory. The introduction of a GPS system (Global Positioning System) was a great achievement, which provided the positioning accuracy of a few meters.

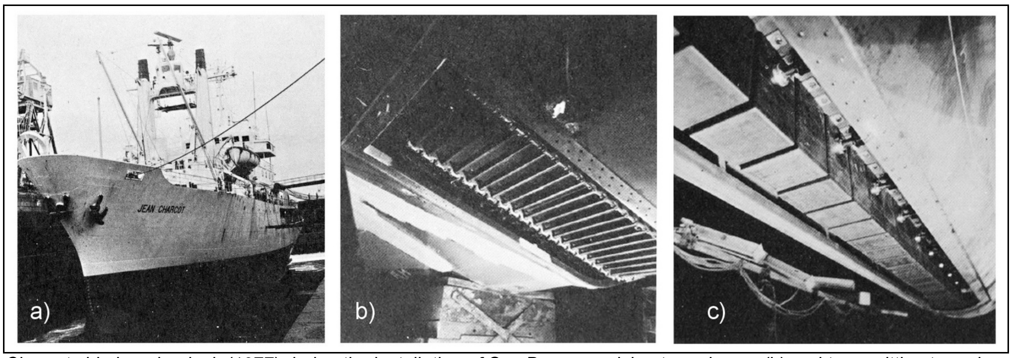

Fig. 3 Jean Charcot ship in a dry dock (1977) during the installation of Sea Beam receiving transducers (b) and transmitting transducers (c) [22].

In 1981, the first German research vessel *Sonne* was equipped with the *Sea Beam* system. A year later a new German *Polarstern* research unit was built to perform research in unknown polar regions of the world. For this purpose *Polarstern* was equipped with a *Sea Beam* sonar capable of measuring depths of 12,000 meters.

Between1984-1986, Krupp Atlas Elektronik in Bremen created the new *Hydrosweep* bathymetric measurement system for use in deep water. The *Hydrosweep* multi-beam echosounder was initially installed on the new German research vessel called *Meteor.* In 1989, a new *Hydrosweep* system with anti-ice protection was installed on board the *Polarstern* research vessel, protecting the active elements of the sonar heads. In 1993 and 1994, the system was upgraded andadjustable swath angle of 90º / 120º was achieved.

Today's systems are definitely different from the prototype *SASS* and *Sea Beam* systems. Since the nineties we have seen an increase in the number of multi-beam systems sold, especially those dedicated to shallow water. The multi-beam sonar technology is systematically enhanced.

Development work includes, among other things, ship pitch sensors, increased computing power and improved visualization methods for bathymetric data. There are echosounders working at higher signal frequencies, with very narrow beams, e.g. 0,4º x 0,7º (Kongsberg EM 2040) or 0,5º x 1º (Teledyne RESON SeaBat 7125).

Since 1990, multi-beam echoes have been used extensively in geological and oceanographic studies, in the extractive industry and cable and submarine pipeline operations. With the drop in unit price of multi-beam echosounder components, the number of models sold has increased significantly.

Modern multi-beam systems are available in the mobile version, which allows for assembly on small boats and motorboats as well as autonomous underwater vessels. These systems work with frequency modulation, they can use the *dual swath* option to provide longitudinal higher data density at higher survey speed, have full pitch, roll and yaw stabilization. *Chirp* technology has enabled the sonar range and measurement resolution to increase, and the pulse length has been reduced to 25 microseconds.

SUMMARY

Multi-beam echosounders has been used for more than forty years in hydrographic survey for marine cartography, shipping safety, navy support, and science development. With the improved resolution and measurement capabilities of these systems, new areas have emerged, where MBES devices are an invaluable aid.

These include the exploration and extraction of natural resources, fisheries, maritime engineering or underwater archaeology. Today, depending on the designation, low frequency MBES (12 kHz - 50 kHz); medium frequency MBES (70 kHz-150 kHz) and high frequencies MBES (above 200 kHz) are produced. The deepest depths of our planet (> 11000 m) are tested by an echosounder with 8 m and 12 kHz transducers. These are heavy transducers installed on essentially large ocean research vessels.

Within the limits of the continental shelf, to the depth of 200 meters, multi-beam echosounders were the largest applications operating in the 70 kHz-200 kHz band. In shallow and very shallow waters (up to a few meters deep), the systems that use signals of 300 kHz to 400 kHz are most effective. These small-size echosounders can be installed on remotely operated vehicle (ROV) and autonomous underwater vehicle (AUV).

Currently, the commercial market offers multi-frequency MBES which are able to operate on different ranges [23]. In these systems, the nominal frequencies of acoustic signals are most commonly used at 200 kHz, 300

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